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Evaluating the relationship between cotton (*Gossypium hirsutum L.*) crop management factors and tarnished plant bug (*Lygus lineolaris*) populations

By

Chase Allen Samples

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Evaluating the relationship between cotton (*Gossypium hirsutum L.*) crop management factors and tarnished plant bug (*Lygus lineolaris*) populations

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Tarnished plant bug is the most important insect pest of cotton in Mississippi. Management of this insect is difficult because of insecticide resistance as well and the overwhelming population densities in many areas of the Mississippi Delta. Given the level of plant bug infestation and damage observed in cotton over the past several growing seasons, information is needed to improve management of vegetative growth once fruit retention is reduced. Little data exists regarding the impact of nitrogen application on infestation by tarnished plant bug. In addition, growers have been progressively reducing seeding rates as seed and technology fees have increased over the past 15 years. Although seeding rates have been reduced, nitrogen application recommendations have not changed. This research was initiated to determine the relationship between crop management factors and tarnished plant bug and to further refine N rate recommendations in the presence of reduced plant populations.

DEDICATION

I would like to dedicate this research first and foremost to my Lord and Savior Jesus Christ. Without Him, none of this would be possible. Next I would like to dedicate this research to my parents, Randy and Sonya Samples, and my grandparents, the late L.A. “Dube”, and Fay Samples. I would not be where I am in life today without their love, support, teaching, and encouragement. They not only have served as an inspiration in pursuing a degree in agriculture due to farming being my family’s livelihood, but the lessons I have learned from these people are truly invaluable and they have molded me into the person I am today. Lastly, I would like to dedicate this research to my loving wife Kelly. She has supported and encouraged every decision I have made up to this point in my education.

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CHAPTER I

INTRODUCTION

Cotton (*Gossypium hirsutum* L.), is an important crop for the local economy in many regions of Mississippi. Cotton was ranked as the fifth most valuable agricultural commodity to the state of Mississippi in 2013 with a $331 million value of production (MDAC, 2013). Botanically, cotton is a perennial shrub, but has been domesticated through breeding to be grown as a pseudo-annual shrub (Chaudhry and Guitchounts 2003). This is acheived through the use of plant growth regulators, harvest aids, and specialized management practices. There are five different species of cotton that have been domesticated. However, upland cotton, also known as Acala, accounts for over 90% of cotton production worldwide (Chaudhry and Guitchounts 2003).

Cotton growth stages are defined in numerous ways including: plant height, total plant nodes, formation of fruiting structures, nodes above white flower, and days after planting. Accumulated heat units, or DD_{60}'s, are also used with regard to cotton management practices. DD_{60}'s are an estimation of accumulated units during a given day and are based on the average of the maximum and minimum daily temperatures (Ritchie et. al 2008). The maximum and minimum daily temperatures are averaged and 60˚F which is considered to be the lowest temperature in˚F at which cotton will grow is subtracted to determine the accumulated DD60's for that day (Table 1.1).

Approximately 4 - 14 days after planting, emergence will occur (Bednarz and Nichols 2005). The first pinhead square is visible and can be identified within 40 days after planting and will be located on node 5 to 7 (Ritchie et al., 2008). Following pinhead square is match head square or "one-third grown" square (Ritchie et al., 2008). Squaring is the term associated with the development of floral prior to bloom. The first bloom occurs approximately 21 days after the first square is visible. Cotton has a three day vertical and six day horizontal flowering/fruiting interval (Jenkins et al., 1990). Once the bloom period begins, the majority of the flowers produced in the first six weeks will produce bolls and be harvested (Ritchie et al., 2008). A flower is pollinated within a few hours of opening. Flowers are white when they first open, then turn pink the second day after opening. Within 5 to 7 days the floral structures dry, turn red in color, and fall off with a formed boll left in its place (Ritchie et al., 2008). At first bloom it is ideal to have approximately 9 to 10 nodes above white flower (NAWF) under optimum growing conditions. As flowering approaches the apical meristem of the plant, all of the plant's energy is shifted into boll development, and further flower development decreases. This stage is referred to as cutout (Ritchie et al., 2008). The time from planting to harvest is approximately 140 days. Under optimum growing conditions a cotton plant will have 20-24 vertical nodes at harvest (Jenkins et al., 1990).

With the eradication of the boll weevil and the development of Bt cotton, the tarnished plant bug [*Lygus lineolaris* (Palisot de Beauvois)] has become the most important insect pest for cotton producers in Mississippi. It is in the Miridae family, the largest family of Hemiptera (Triplehorn and Johnson 2005). All mirids have piercing and sucking mouthparts (Triplehorn and Johnson 2005). The tarnished plant bug has a gradual life cycle and will pass through five instars before reaching adulthood. Multiple generations occur each year, but generations overlap by the time tarnished plant bug infests cotton. In cotton, tarnished plant bug eggs are usually inserted into plant structures with most eggs being deposited in squares and terminals. Tarnished plant bugs usually complete one or more generations on alternate hosts prior to moving into cotton fields (Layton 1995). Additionally, tarnished plant bug populations increase more rapidly in wetter years than in drier years as the tarnished plant bug proliferates on alternate hosts and moves into cotton during the reproductive stages (Layton 1995). Tarnished plant bugs can have an effect on cotton at any stage. However, cotton is most susceptible to damage beginning at first bloom (Black 1973). Most damage caused by the tarnished plant bug is not from mechanical damage during feeding, but rather the injection of the digestive enzymes. These enzymes breakdown plant tissues that the insect has fed upon (Layton 1995). The saliva injection site is localized and is not systemic.

Sampling tarnished plant bug typically performed with a 38 cm diameter sweep net (Young and Tugwell 1975). Sweeps should be conducted through the top of the canopy and should be randomly located from the previous sweep so that the net is not passing through an area that has already been disturbed. Typically, 25 sweeps are collected from each row and the population is determined based on the number of tarnished plant bugs per 100 sweeps (Layton 1995).

Sampling for nymphs should be performed using a drop cloth (Snodgrass 1993). A three foot wide drop cloth that has two wooden dowels along each edge is stretched across 0.91meters between two rows. The plants on each side are beaten vigorously over the top of the cloth to dislodge the nymphs causing them to fall on the cloth. Typically, adults are flushed from the canopy using this method, making ti a less effective way to sample adults. Nymph infestations are counted and expressed as number per six row feet or number per row foot (Layton 1995). Monitoring square retention can also help with making insecticide application decisions for tarnished plant bug, especially during preflowering stages. Square retention is monitored by examining the uppermost five fruiting nodes and counting squares retained compared to squares abscised (by visually finding abscission scars).

In recent years, consultants and entomologists have observed increased difficulty managing tarnished plant bugs. Insecticide rates have increased and treatment intervals have decreased to manage existing populations. However, management has remained difficult. One reason for increased difficulty in managing tarnished plant bug with insecticides may be due to insecticide resistance. Tarnished plant bug populations resistant to organophosphate insecticides were documented in 2009 (Snodgrass et al., 2009). Snodgrass and Scott (1988) found that tarnished plant bugs collected from the Mississippi Delta were more resistant to dimethoate (Cygon) than those collected from areas where fewer insecticides were used (Snodgrass and Scott 1988). Snodgrass (1994) also reported tarnished plant bug populations collected from the Mississippi Delta were 54-fold more tolerant to permethrin and 35-fold more tolerant to bifenthrin than other insect species. Increased corn acres have likely influenced tarnished plant bug population trends, as corn is a host prior to senescence. Upon corn senescence, tarnished plant bugs move into cotton (Snodgrass 1984b). As a result, populations of tarnished plant bug migrate into cotton during July and August where they are exposed to insecticides and selected for resistance (Snodgrass et al., 2009).

Efficient N nutrition of cotton is critical not only for successful production, but also minimize excess nitrogen in the environment (McConnell et al., 2008). N fertilizer is used on over 90% of the cotton acres in the U.S. to optimize growth and maximize profit (Fertilizer Inst. 1998). Mississippi State University enterprise budgets suggest that the average cost per hectare of nitrogen fertilizer (UAN 32%) in a conventional tillage system that is furrow irrigated in the Delta area is $210.64 (Mississippi State University, 2012). Nitrogen is commonly applied every year due to its movement throughout the soil and its use by the plant. Nitrogen levels vary across a given field due to the amount of N removed by a crop during the growing cycle as well as through varying soil types across a field, volatilization, denitrification, leaching, and runoff (Mallarino and Wittry 2004). Nitrogen is a key element in growth and maturity of cotton. Cotton yield potential is strongly influenced by N availability (Clawson et al., 2006). Crop rotation must also be considered when determining N application rates for cotton. When cotton is rotated with corn, increased yield has been observed with reduced rates of N applied (Boquet et al., 2009).

The use of plant growth regulators has become common in cotton production in the United States. The most commonly used plant growth regulator is mepiquat chloride. Applications of mepiquat chloride reduce internode elongation and plant height. Reduced internode elongation and plant height are due to reduced gibberellic acid in plant tissues (Nuti et al., 2006; Reddy et al., 1990; Zhao and Oosterhuis, 2000). Reduced gibberellic acid causes stiffened cell walls and reduced elongation and division of cells (Behringer et al., 1990; Biles and Cothren, 2001; Yang et al., 1996). Commercial plant growth regulators can reduce the number of mainstem nodes, and decrease plant heights compared to the untreated control regardless of the product used (Dodds et al., 2010)

Seed premiums, technology fees associated with transgenic technology, and the use of seed treatments have increased at-planting costs and have caused renewed interest in reduced plant populations (Siebert and Stewart, 2006). Cotton is planted in a variety of row configurations and plant populations. However, the overall establishment of an acceptable population in cotton is critical for obtaining high yield (Christiansen and Rowland 1981). An acceptable plant population varies by location, environment, cultivar, and grower preferences (Silvertooth et al., 1999).). Previous research indicates that maximum yields in the Mississippi Delta were obtained with a population range between 7.0-12.1 plants m^{-2}. Fowler and Ray (1977) suggested that the optimum plant populations for cotton in Texas were between 7.9-15.5 plant m^{-2}. In addition, Hicks et al. (1989) found optimum plant populations for Texas were between 7.0-14.0 plants m^{-2}.

There is an overall need to further understand how selected management practices impact cotton production systems. Given environmental issues associated with nitrogen use in agriculture, continued research as to how to refine use patterns and efficiency of nitrogen fertilizer is needed. Furthermore, little data exists regarding the impact of nitrogen application on infestation by tarnished plant bugs. Tarnished plant bugs have become the number one pest of cotton in Mississippi. Tarnished plant bug management is made more difficult through the occurrence of insecticide resistance as well as the overall number of insecticide applications required to produce a crop. Agronomic practices that are interrelated to tarnished plant bug infestation and management must be quantified and adjusted if need be to maximize fertilizer use as well as minimize impact of tarnished plant bug infestation. Also, given the level of plant bug infestation and damage observed over the past several growing seasons, information is needed on managing vegetative growth of cotton once fruit retention is reduced. In addition, growers have been progressively reducing seeding rates as seed and technology fees have increased over the past 15 years. However, even though overall plant populations are reduced, nitrogen application recommendations have not changed. Research is needed to determine if nitrogen application rates should be adjusted to account for the reduction in seeding rates and resultant plant populations.

Table 1.1 General summary of het unit accumulations and the average number of days after planting required to reach each physiological growth stage.

Growth Stage	Heat Units	Days After Planting
Emergence	50	5
First Square	550	38
First Flower	950	59
Open Boll	2150	116
Harvest	2600	140

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CHAPTER II

IMPACT OF NITROGEN RATE ON TARNISHED PLANT BUG POPULATIONS AND MANAGEMENT

Introduction

The tarnished plant bug [*Lygus lineolaris* (Palisot de Beauvois)] is the primary insect pest of cotton in Mississippi, as well as most of the mid-southern growing region of the U.S. Williams (2013) showed in 2012, 99% of the cotton (*Gossypium hirsutum* L.), hectares planted in the Delta region of Mississippi were infested with tarnished plant bugs. Nearly 95% of these hectares received an average of six insecticide applications for tarnished plant bugs during the growing season. The average cost for a single tarnished plant bug application was $32.85 per hectare per growing season. Increased inputs for control of a single pest, as well as seed premiums, technology fees associated with transgenic seed varieties, seed treatments, increased herbicide use due to resistant weed species, higher fuel costs, increased fertilizer costs, and costs for controlling other insect pests has led to greatly increased costs associated with cotton production.

Control of tarnished plant bugs in cotton has become more challenging due to insecticide resistance. Snodgrass (1994) reported that tarnished plant bug populations in the Mississippi Delta were 54-fold more tolerant to permethrin and 35-fold more tolerant to bifenthrin than other populations. Snodgrass (1996) documented resistance to the pyrethroid insecticides in field populations of tarnished plant bugs in 1996. Snodgrass and Scott (1988) found that tarnished plant bugs collected from the Mississippi Delta were more resistant to dimethoate (Cygon) than those collected from other areas of Mississippi. In addition, resistance to other organophosphate insecticides was documented in 2009 (Snodgrass et al., 2009). Increased corn acres have also contributed to increased tarnished plant bug populations as corn serves as a host prior to senescence. Upon corn senescence tarnished plant bugs move into cotton (Snodgrass 1984b). As a result, increased populations of tarnished plant bugs in cotton have been observed during July and August where they are subject to exposure to insecticides (Snodgrass et al., 2009).

Due to the increased cost and difficulty controlling this pest, different integrated pest management strategies are being evaluated for tarnished plant bug management. Adams et al. (2013) found that planting between mid-April and early May could reduce the number of insecticide applications for tarnished plant bug in a given year. They also observed that planting in mid-April significantly increased yields when compared to planting in early May, mid-May, and early June. In the same study, earlier maturing cotton yielded significantly more than the late maturing cotton regardless of the number of insecticide applications. In addition, early maturing cotton treated for tarnished plant bug based on established thresholds yielded significantly greater than a later maturing cotton regardless of insecticide application. Managing for earliness through planting date and varietal maturity selection may maximize yield and reduce insecticide input costs.

Tarnished plant bug is attracted to vigorous growing, vibrant cotton (Willers et al., 1999). Excessive N application to cotton can result in increased plant height as well as increased vegetative growth, that could alter maturity (Varco et al., 1999). In 2007, the average amount of N applied per hectare in Mississippi was 131 kg/ha (NASS 2007). While optimum N application rates vary by region, growing conditions, and soil types, previous research indicates that cotton yields are maximized at 90 kg of N applied per hectare (Parvin et al., 2003). Increased N rates could potentially attract more tarnished plant bugs into a given field. Excessive N rates could also potentially delay crop maturing allowing for longer infestation times from tarnished plant bug. Given the status of tarnished plant bug resistance to insecticides and the cost required to control this pest, adjusting N rates could potentially make cotton less attractive to tarnished plant bug and allow the crop to mature faster. This could potentially alleviate late season applications for tarnished plant bug, while maintaining yield, resulting in economic benefits for many growers across the mid-southern growing region. Little to no data exists regarding the effects of N rate on infestation and control of tarnished plant bug in cotton. Therefore, this project was initiated to evaluate the effect of N application rate on tarnished plant bug infestation and management in cotton.

Materials and Methods

An experiment was conducted in Stoneville, MS at the Mississippi State University Delta Research and Extension Center in 2012 and 2013 to evaluate the effect of fertilizer N application rate on tarnished plant bug infestation and yield. Stoneville 5288 B2RF was planted at a rate of 12.6 seeds per m of row on conventionally tilled beds on 01 May 2012, and 14 May 2013. A variety expressing two Bt genes was used to minimize the impact of lepidopteran pests on cotton yields. Seed were also treated with a commercial premix of imidacloprid, metalaxyl, ipconazole, and thiodicarb (Aeris, Bayer CropSciences, Monheim am Rhein, Germany). A natural infestation of tarnished plant bugs was utilized in both years. Prior to cotton establishment, a wheat (*Triticum aestivum* L.) cover crop was planted to reduce the level of N remaining from previous years. Plots were maintained in the same location using the same randomization to avoid confounding effects of N availability. Soils in the area where experiments were conducted were classified as a mix of Beulah very fine sandy loam (coarse-loamy, mixed, active, thermic Typic Dystrudepts) and a Bosket very fine sandy loam (fine-loamy, mixed, active, thermic Mollic Hapludalfs). Cotton was furrow irrigated as needed for the duration of the study. Nitrogen was applied as 32% urea-ammonium nitrate (UAN) in a single application made at pinhead square. Nitrogen was applied using a liquid applicator equipped with a John Blue piston pump driven by an AccuRate Rawson hydraulic drive controller. Plots consisted of 16 rows spaced 102 cm apart that were 22.9m in length. Plant growth regulators were applied as needed to all plots. Plots were harvested on 04 October 2012 and 10 October 2013.

This experiment was conducted using a factorial arrangement of treatments within a randomized complete block design. Factor A consisted of fertilizer N application rate and included 0, 44, 90, 134, and 179 kg N ha $^{-1}$. Factor B consisted of management of tarnished plant bug and included treatments applied based on Mississippi State University Extension Service threshold or no treatment for tarnished plant bug. All plots were scouted once per week. During the pre-flowering stages, tarnished plant bug densities were determined by taking 25 sweeps with a 38cm diameter sweep net in each plot. Prior to flowering, each sprayed plot was treated as needed when the overall average number of tarnished plant bugs from all replications reached threshold (eight tarnished plant bugs per 100 sweeps) (Catchot, 2013). During the flowering stages, all plots were sampled once weekly with a black drop cloth. Two drop cloth samples were collected per plot. The total number of tarnished plant bug adults and nymphs per sample was recorded. Insecticide applications were made when the overall average number of tarnished plant bugs from all replications reached threshold (three tarnished plant bugs per 1.5 meters of row) (Catchot, 2013). Plots were treated with insecticides and insecticide mixtures to maximize tarnished plant bug control. Insecticides included organophosphates, pyrethroids, insect growth regulators, carbamates, neonicotinoids, and sulfoxamines. Insecticides were rotated during the year for resistance management purposes. Insecticide applications were terminated when nodes above white flower reached five plus 300 heat units. Nodes above white flower were determined by counting the number of mainstem nodes above the uppermost first position white flower (Bourland et al., 1992). Russell et al. (1999), found that bolls that have accumulated at least 300 heat units did not sustain further damage due tarnished plant bugs. Additional data collection consisted of plant height (cm) and total nodes at pinhead square; plant height (cm), total nodes, and nodes above white flower at first bloom; as well as plant height (cm), total nodes, nodes above cracked boll, and node of first fruiting branch immediately prior to defoliation. All data were collected from five randomly selected plants per plot. All other agronomic practices were performed based on Mississippi State University Extension Service recommendations. Seed cotton yield was determined at physiological maturity by harvesting rows 5, 6, 11, and 12 with a John Deere 9900 two row spindle type picker equipped for small plot research. Yields were adjusted to kg ha^{-1}. Turnout was determined by removing a grab sample from each harvested sample. This sample was then ginned using a 10 saw Continental Eagle laboratory gin. Once each sample was ginned, turnout was calculated by divinding the weight of the cotton lint after ginning by the seed cotton weight prior to ginning and multiplying by 100. Cotton fiber was sent to Louisiana State University Fiber Quality Laboratory where fiber quality was determined using high volume instrumentation (HVI).

Cotton height, total nodes, and nodes above white flower at first bloom, height, total nodes, nodes above cracked boll at the end of the season, seed cotton yield, and lint yield means were calculated for each replicate for each year. Each measurement was initially regressed on N rate allowing for both linear and quadratic terms with coefficients depending on N rate, presence of insecticide applications for tarnished plant bugs, and year. Insignificant ($P \leq 0.05$) model terms were removed sequentially and the model was refit until a satisfactory model was obtained. All statistical analyses were conducted using SAS v. 9.3. (SAS Institute Inc., Cary NC)

Results and Discussion

There was no interaction between N application rate, tarnished plant bug management, and environment for data measurments collected prior to flowering. However, environment alone was significant. Prior to flowering, no statistical differences between sprayed and unsprayed plots at any N application rate were present. However, plant height and number of nodes prior to flowering in 2013 were generally less than those from 2012 (data not shown).

There was no interaction between N application rate, tarnished plant bug management, and environment for cotton height and number of nodes at first flower. Environment alone was significant for cotton height at first flower, number of nodes at first flower, and nodes above white flower. Cotton was generally taller and had more nodes in 2012 compared to 2013 (data not shown). Cotton plants in 2013 had a greater number of nodes above white flower when compared to plants in 2012. This is an indication of having greater yield potential at first flower with plots in 2013 than those in 2012.

Cotton height at the end of the season was significantly affected by N rate and is best described using a nonlinear (quadratic) trend (Table 2.1). The rate of linear increase in cotton height was dictated by the presence or absence of insecticide applications for plant bugs (Table 2.2). Generally, cotton grown in 2012 was taller at the end of the season compared to cotton grown in 2013 (Figure 2.2). Height of cotton grown in the absence of insecticide applications for plant bugs increased linearly at a rate of 0.27 cm for each additional increase in kg N ha^{-1}. However, cotton height was maximized at 170 kg N ha^{-1} and after which each additional increase in kg N ha $^{-1}$ cotton height maintained relatively the same. Cotton height in the presence of insecticide applications significantly increased linearly at a rate of 0.21 cm and peaked at a rate of 128 kg N ha^{-1} (Table 2.2). However, cotton height in the presence of insecticide applications maintained relatively similar once absolute agronomic peak was met. Generally, differences in height could be associated with responses to N fertility from year to year. Main et al. (2013) observed that residual N is in many of the soils used to produce cotton. If a high level of residual N was present at time of fertilization, differences in cotton height associated with the higher nitrogen application rates may have been difficult to delineate. However, based on the trend in cotton height response to N there is a potential for cotton grown at rates higher than 90 kg N ha^{-1} to produce taller plants. This is in agreement Main et al. (2013) who observed that increasing N rates can increase plant height. However, based on these data, cotton height at the end of the season in the absence of plant bug control is maximized following an application of 170 kg N ha^{-1} (Figure 2.3). Conversely, cotton height at the end of the season grown in the presence of plant bug control is maximized following an application of 128 kg N ha^{-1}.

Mainstem cotton nodes at the end of the season were significantly affected by N rate (Table 2.1). The effect of N rate on number of mainstem nodes is described as nonlinear (quadratic). Similar to the effect of N rate on cotton height at the end of the season, a linear increase with respect to mainstem nodes was dependent on the presence or absence of insecticide applications for plant bug control (Table 2.1). Generally, cotton grown in 2013 produced fewer mainstem nodes than cotton grown in 2012. Total nodes at the end of the growing season in both 2012 and 2013 significantly increased in a linear manner at a rate of 0.046 nodes for each additional kg N ha^{-1} applied. Conversely, mainstem of cotton grown in the presence of insecticide applications significantly increased at a rate of 0.03 nodes with each addition kg N ha^{-1}applied. However, regardless of insecticide applications, cotton nodes were observed to stay relatively similar to the absolute agronomic peak after it was attained. Based on these values, mainstem nodes of cotton in the presence of insecticide applications are maximized at N rates of 137 kg N ha^{-1} (Figure 2.2). In the absence of applications for tarnished plant bug, mainstem node predictions are unattainable due to values falling outside of testing constraints. Variability in mainstem node counts declined, thus causing the r^2 value to increase to 0.63.

Nodes above cracked boll (NACB) were significantly affected by N rate (Table 2.1). The relationship between N fertilization rate and NACB is linear in nature.

However, similar to cotton heights and mainstem nodes at the end of the season, results differed in the presence of insecticide applications for plant bug control (Table 2.4). Linear increases in NACB in the presence of insecticide applications for plant bug control were found to be insignificant in both years. In the absence of insecticide applications, NACB significantly increased as N rate increased. This would suggest that when tarnished plant bugs are allowed to flourish in cotton, and N rates are increased, maturity can be delayed. Layton (1995) observed that when cotton fruiting structures were fed upon by plant bugs, square abscission can occur leading to delayed maturity. Main et al. (2013) observed that increasing N rates led to increased NACB thus delaying maturity. Data from the unsprayed portion of this experiment would tend to agree with both Layton (1995), and Main et al. (2013).

Tarnished plant bug densities varied by year as well as in sprayed and unsprayed plots. However N application rate did not have an impact on tarnished plant bug densities until later in the year. Regardless of N application rate and insecticide use during the flowering period of cotton, plant bug densities could not be maintained below the recommended threshold throughout the growing season. However, a 4-fold increase in plant bug density was observed in the unsprayed plots compared to the sprayed plots across both years of the study at all N application rates (Figure 2.4 and 2.5). The number of insecticide applications made based on the action threshold varied between years. In 2012, more insecticide applications were needed due to a larger population density when compared to 2013 (Table 2.6). In 2012, the number of insecticide applications needed generally increased as the total amount of N applied increased. Tarnished plant bug response to N fertilization in 2013 was similar to 2012 with the exception of the 45 kg ha^{-}

^{1} N application rate. An increase in the number of insecticide applications applied following an application of 44 kg N ha^{-1} was observed compared to 90 kg N ha^{-1}. This could be due to little difference in early season cotton growth and development between the sprayed treatments. Across both years, plots recieving 134 kg N ha^{-1} and 179 kg N ha^{-1} consistently maintained tarnished plant bugs above the economic threshold during the later portion of the flowering period regardless of insecticide application. This could be attributed to a significant increase in cotton height (Figure 2.2) and mainstem nodes (Figure 2.3). The general trend between N fertilization rates and total nodes at the end of the season, also highlights the relationship between increased insecticide applications at the higher N application rates in 2012 and 2013, respectively (Table 2.5). If more nodes were present, penetrating the canopy could become more difficult due to an increase in canopy density. Increased plant height and mainstem nodes, could hinder insecticide penetration into the canopy due to increased vegetative growth. The mean number of applications for tarnished plant bugs made based on the action threshold generally increased as the level of N applied increased.

Cotton lint yield was significantly affected by N rate and was described as a nonlinear (quadratic) trend with an r^2 value of 0.83 and a confidence interval of <0.0001 at all intercepts, linear terms, and quadratic terms. However, results differed by year in response to N rate (Fig. 2.3). Generally cotton grown in the absence of insecticide applications for tarnished plant bug yielded less than cotton grown in the presence of insecticide applications in both years (Fig. 2.3). Cotton grown in 2013 had a greater response to N than cotton grown in 2012. Cotton lint yield in 2012 increased at a linear rate of 4.4 kg lint ha^{-1} with each additional kg N ha^{-1} applied (Table 2.5). Comparatively, cotton lint yield in 2013 increased linearly at a rate of 6.8 kg lint ha^{-1} with each additional kg N ha^{-1} applied. However, once peak agronomic yield was attained in both years, yield significantly decreased at a rate of 0.2 kg lint ha^{-1} with each additional kg N applied. Differences among years could be associated with differences in environment between years. Based on the regression model, absolute agronomic yield in 2012 was 1438 kg lint ha^{-1} and was attained at an N rate application of 97 kg N ha^{-1}. Absolute agronomic yield in 2013 was 1746 kg lint ha $^{-1}$ and was attained at a rate of 152 kg N ha $^{-1}$. Data from 2012 agrees with McConnell et al. (2000) and Main et al. (2013) in that yields are maximized when N application rates between 90 and 112 kg ha^{-1}. Based on these data, absolute agronomic yield of cotton is attained between the rates of 96 -151 kg N ha^{-1} depending on the year.

Fiber uniformity and strength was not affected by N rate, year, or the presence of insecticide applications for plant bug control (Table 2.6). However, fiber length did differ among year. Cotton grown in 2012 had increased fiber length compared to cotton grown in 2013 (Table 2.7). Cotton grown in the absence of insecticide applications for tarnished plant bug control was observed to have significantly greater fiber length than cotton grown in the presence of these applications in 2013 (Table 2.7). However, no differences were observed among treatments in a given year. Micronaire was significantly affected by N rate (Table 2.6). Treatments receiving ≥45 kg N ha^{-1} had reduced micronaire compared to cotton that received no N fertilization. Microniare for cotton grown in the presence of applied N ranged from 4.6 -4.7 respectively. Microniare of cotton grown in the absence of applied N across both years averaged a micronaire of 4.9.

Net profit over variable cost was maximized in the sprayed and unsprayed portion of the test when N application rates of 90 kg ha^{-1} were applied. Where mean net return was maximized in the unsprayed portion of the test, net returns were no greater than areas of the sprayed portion that received no nitrogen. When yield was optimized in the unsprayed portion of this study [(90 kg ha^{-1} + stnd. dev. 254.34)]; net returns over variable costs were only as high as the mean net returns for the sprayed portion that recieved 44 kg N ha^{-1} (Table 2.8). Variability (mean standard deviation) was greater in all unsprayed portions compared to the sprayed portion, with a greater chance of yield reductions. Plots receiving no N provided more consistent results when comparing standard deviations. However, yield was much lower than all N application rates. The likelihood of yield following application of 44, 90, 134, and 179 kg ha^{-1} being equal to yield following no N application is minimal. However, instances where plots receiving 134 and 179 kg N ha^{-1} yielding greater than plots receiving 90 kg N ha^{-1} are feasible. In this instance a greater distribution exists, thus increasing risk. Therefore, a greater probability in observing lower yields in plots receiving N rates of 134 and 179 kg N ha^{-1} compared to 90 kg N ha^{-1} exists. Average profit was higher for sprayed treatments containing 90 kg ha^{-1}. In addition, the distribution was narrower when compared to the sprayed plots receiving of 134 and 179 kg N ha^{-1}. Plots receiving 0 and 40 kg N ha^{-1} have a much narrower distribution; however, they consistently yielded less and had much lower mean profit when compared to the 90 kg ha^{-1} treatment.

Conclusion

Nitrogen application had a significant effect on cotton height, mainstem nodes, NACB, and lint yield at the end of the season (Figures 2.1, 2.2, 2.3, 2.4). Nitrogen application also had a significant impact on net profit above variable costs. Based on these data, absolute agronomic yields of cotton are consistently maximized following application of 96 to 151 kg N ha^{-1}. Observations by McConnell et al. (2000) and Main et al. (2013) fall within this range of applied rates. Risk associated with N application rates greater than 90 kg N ha^{-1} increased across years in treatments receiving insecticide applications for tarnished plant bug control. Based on these data, growers could potentially reduce the amount of N being applied and still maintain similar yields. These data also suggest that the number of insecticide applications for tarnished plant bug control can be reduced. These reductions could potentially be due to reduced vegetative growth related to a reduction in N rates. Reducing insecticide applications and reducing application costs increases net return on investment due to less variable cost. Growers should consider reducing N application rates and, in turn, potentially reducing the number of applications required to keep tarnished plant bug densities below economic threshold. In addition financial risk is reduced when lowering N application rates.

Table 2.1 Analysis of variance for regression for cotton grown in 2012 and 2013 in Stoneville, MS

Effect	D.F.[H]	FBHT[A]	FBN[B]	NAWF[C]	EOSHT[D]	EOSN[E]	NACB[F]	LINTYLD[G]
					---P value---			
Year	1	<0.0001	<0.0001	<0.0001	0.0005	0.0002	0.0001	--
TPB App.	1	--	--	--	--	--	--	<0.0001
Year*TPB App	1	--	--	--	--	--	0.0002	--
N rate	4	--	--	--	0.0005	<0.0001	0.0006	<0.0001
N rate*Year	4	--	--	--	--	--	--	<0.0001
N rate*TPB App	4	--	--	--	0.0024	<0.0001	0.0376	--
N rate * Year *TPB App	4	--	--	--	--	--	--	--
N rate*N rate	16	--	--	--	0.0253	0.0003	--	<0.0001
N rate * N rate * Year	16	--	--	--	--	--	--	--
N rate * N rate * TPB App	16	--	--	--	--	--	--	--
N rate*N rate * Year*TPB App	16	--	--	--	--	--	--	--

[A] height of cotton at first bloom

[B] mainstem nodes of cotton at first bloom

[C] Nodes above white flower of cotton at first bloom

[D] Height of cotton at the end of the season

[E] Mainstem nodes of cotton at the end of the season

[F] Nodes above cracked boll of cotton at the end of the season

[G] Lint yield of cotton

[H] Degrees of Freedom

Table 2.2 Regression coefficients for cotton height at the end of the season as affected by N rate (kg N ha^{-1}) and insecticide applications in Stoneville, MS

Year	TPB app.[B]	Intercept	Linear	Quadratic
			--------------------Coefficient†------------------	
2012	Unsprayed	93.0675	0.2738‡	-0.0008‡
	Standard Error	2.7645	0.0670	0.0004
	Sprayed	93.0675	0.2068‡	-0.0008‡
	Standard Error	2.7645	0.0670	0.0004
2013	Unsprayed	84.1743	0.2738‡	-0.0008‡
	Standard Error	2.8228	0.0670	0.0004
	Sprayed	84.1743	0.2068‡	-0.0008‡
	Standard Error	2.8228	0.0670	0.0004
Model r^2			0.4240	

† Where Y= cotton height at the end of the season and X =N rate (kg N ha^{-1})

‡ Coefficient was found different than zero or not different based on p values

[A] Tarnished plant bug application

Table 2.3 Regression coefficients mainstem cotton nodes at the end of the season as affected by N rate (kg N ha^{-1}) and insecticide applications.

Year	TPB app.^{A}	Intercept	Linear	Quadratic
			——Coefficient†——	
2012	Unsprayed	18.0585	0.0458‡	-0.0001‡
	Standard Error	0.3225	0.0078	0.00004
	Sprayed	18.0585	0.0329‡	-0.0001‡
	Standard Error	0.3225	0.0078	0.00004
2013	Unsprayed	16.9985	0.0458‡	-0.0001‡
	Standard Error	0.3293	0.0078	0.00004
	Sprayed	16.9985	0.0329‡	-0.0001‡
	Standard Error	0.3293	0.0078	0.00004
Model r^2			0.6294	

† Where Y= nodes of cotton at the end of the season and X =N rate (kg N ha^{-1})

‡ Coefficient was found different than zero or not different based on p values

^{A} Tarnished plant bug application

Table 2.4 Regression coefficients for cotton nodes above cracked boll at the end of the season as affected by N rate (kg N ha^{-1}) and insecticide applications.

Year	TPB app.^{A}	Intercept	Linear
		Coefficient†	
2012	Unsprayed	0.5442	0.0208‡
	Standard Error	0.6148	0.0052
	Sprayed	0.6682	0.0054
	Standard Error	0.6099	0.0051
2013	Unsprayed	2.3479	0.0208‡
	Standard Error	0.6284	0.0052
	Sprayed	2.4718	0.0054
	Standard Error	0.6009	0.0051
Model r^2		0.3587	

† Where Y=NACB of cotton at the end of the season and X =N rate (kg N ha^{-1})

‡ Coefficient was found different than zero or not different based on p values

^{A}Tarnished plant bug application

Table 2.5 Regression coefficients for cotton lint yield of cotton (kg lint ha^{-1}) as affected by N rate (kg N ha^{-1}) and insecticide applications

Year	TPB app.^{A}	Intercept	Linear	Quadratic
		————Coefficient†————		
2012	Unsprayed	827.9469	4.3569‡	-0.0225‡
	Standard Error	38.4399	0.9481	0.0049
	Sprayed	1227.1772	4.3569‡	-0.0225‡
	Standard Error	39.2813	0.9481	0.0049
2013	Unsprayed	827.9469	6.8286‡	-0.0225‡
	Standard Error	38.4399	0.9629	0.0049
	Sprayed	1227.1772	6.8286‡	-0.0225‡
	Standard Error	39.2813	0.9629	0.0049
Model r^2			0.8340	

† Where Y= Lint yield (kg lint ha^{-1}) and X =N rate (kg N ha^{-1})

‡ Coefficient was found different than zero or not different based on p values

^{A} Tarnished plant bug application

Table 2.6 Number of insecticide applications based on economic threshold tarnished plant bug at each nitrogen rate (kg N ha^{-1})

N rate (kg N ha^{-1})	2012	2013	Mean
0	3	2	2.5
45	4	3	3.5
90	4	2	3
134	5	3	4
179	5	4	5

Numbers in the same column were applied at the same year. Mean is the average number of applications made across each year at each level of nitrogen.

Table 2.7 Effects of insecticide application, nitrogen rate, and year alone on fiber length, uniformity, strength, and micronaire.

Effect	D.F. [A]	Length	Uniformity	Strength	Micronaire
		----------------------------P value----------------------------			
Sprayed	1	0.51	0.97	0.56	0.17
N rate	4	0.12	0.31	0.08	0.02
Sprayed * N rate	4	0.79	0.96	0.55	0.17
Year	1	0.04	0.08	0.11	0.88
Year * N rate	4	0.75	0.20	0.77	0.13
Year * Sprayed	1	0.03	0.92	0.37	0.40
Year * Sprayed * N rate	4	0.07	0.32	0.30	0.59

[A] Abbreviation=Degrees of Freedom

Table 2.8 Effect of spraying and year on cotton fiber length (cm).

Year	Sprayed	Fiber Length
2012	No	2.98 a
	Yes	2.96 ab
2013	No	2.93 b
	Yes	2.95 b

Means within a column followed by the same letter are not significantly different at ($P \leq 0.05$)

Table 2.9 Effect of N rate (kg N ha^{-1}) on cotton micronaire.

N rate (kg N ha^{-1})	Micronaire
0	4.9 a
45	4.6 b
90	4.7 b
134	4.6 b
179	4.6 b

Means within a column followed by the same letter are not significantly different at ($P \leq 0.05$)

Table 2.10 Analysis of economic gains above variable cost with associated standard deviations for risk analysis for mean yield values across both years of study.

Nitrogen Application Rate (kg ha^{-1})	Sprayed	Mean Lint Yield (kg/ha)	Standard Deviation of Lint Yield (kg/ha)	Mean Lint Yield (kg/ha) - Stnd. Dev. (kg/ha)	Mean Lint Yield(kg/ha) + Stnd. Dev. (kg/ha)	Mean Profit ha^{-1}	Standard Deviation of Profit	Mean Profit ha^{-1} – Stnd. Dev. $	Mean Profit ha $^{-1}$ + Stnd. Dev. $
0	No	785	333.56	451	1119	602.98	240.93	362.05	843.91
44	No	1029	187.53	841	1217	810.74	404.89	405.84	1215.64
90	No	1138	254.34	884	1392	969.50	549.12	420.38	1518.62
134	No	1129	293.89	835	1423	871.77	634.51	237.26	1506.28
179	No	1099	291.51	807	1391	731.28	629.37	101.91	1360.65
0	Yes	1135	95.71	1039	1231	993.05	227.45	765.60	1220.50
44	Yes	1464	182.54	1281	1647	1576.04	413.19	1162.84	1989.24
90	Yes	1616	258.52	1357	1875	1851.76	602.98	1248.78	2454.74
134	Yes	1517	424.04	1093	1941	1514.38	963.57	550.81	2477.95
179	Yes	1559	333.29	1226	1892	1501.19	743.37	757.82	2244.56

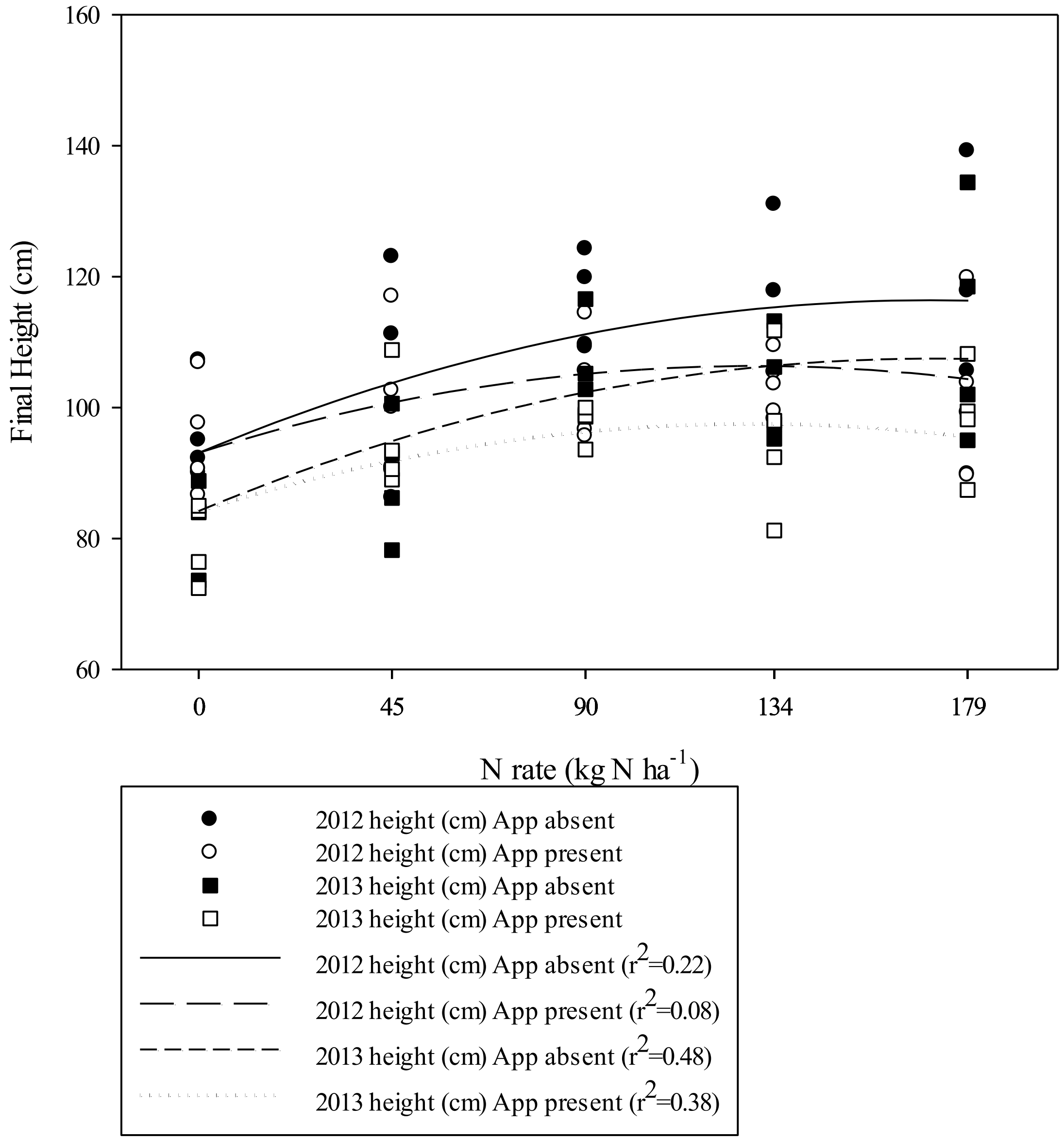

Figure 2.1 Effect of N rate (kg N ha^{-1}), presence of insecticide applications for tarnished plant bug control, and year on end of the growing season cotton heights in Stoneville MS in 2012 and 2013.

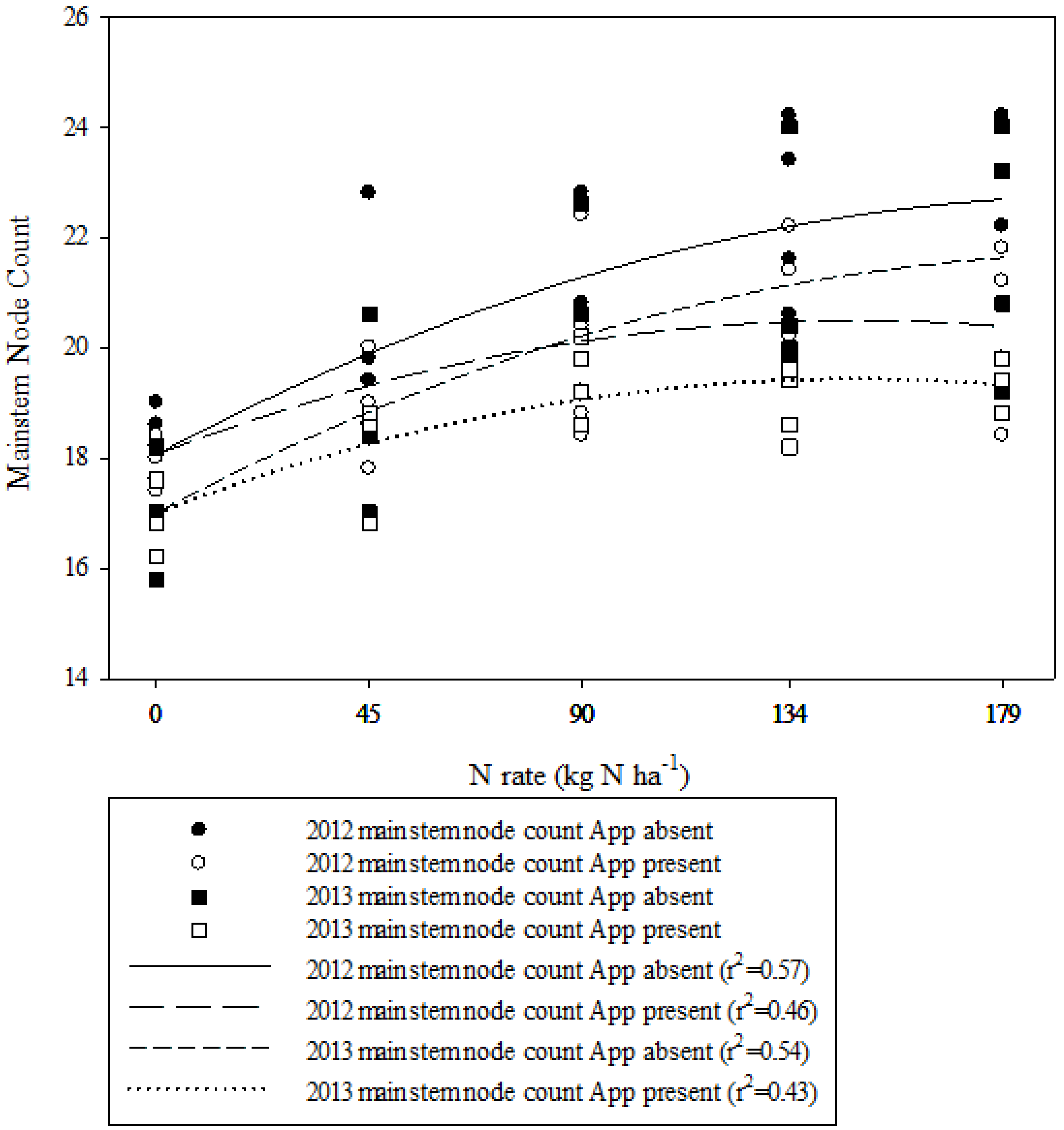

Figure 2.2 Effect of N rate (kg N ha^{-1}), presence of insecticide applications for tarnished plant bug control, and year on cotton mainstem nodes at the end of the growing season in Stoneville MS.

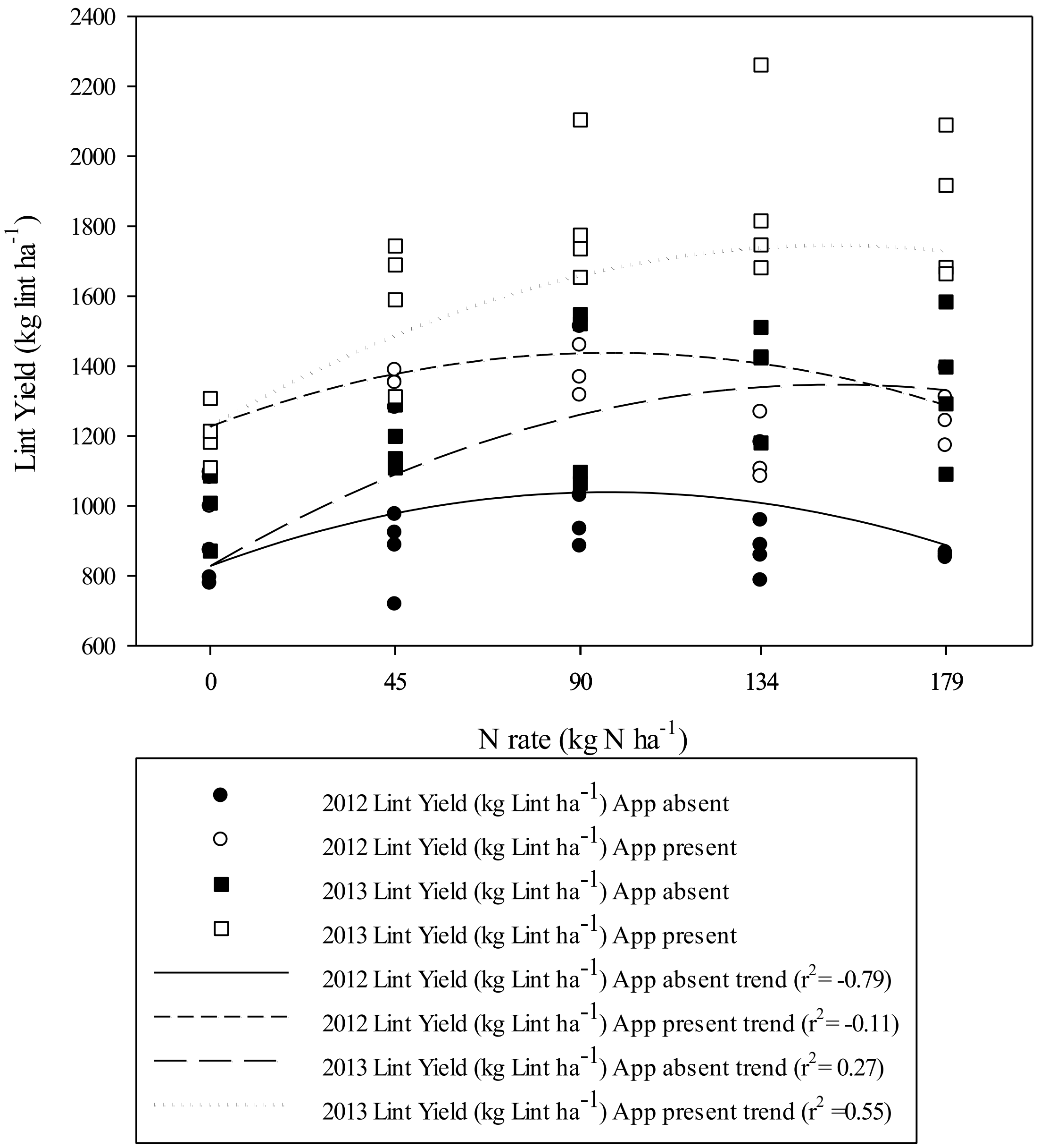

Figure 2.3 Effect of N rate (kg N ha^{-1}), presence of insecticide applications for plant bug control, and year on cotton lint yield in Stoneville, MS.

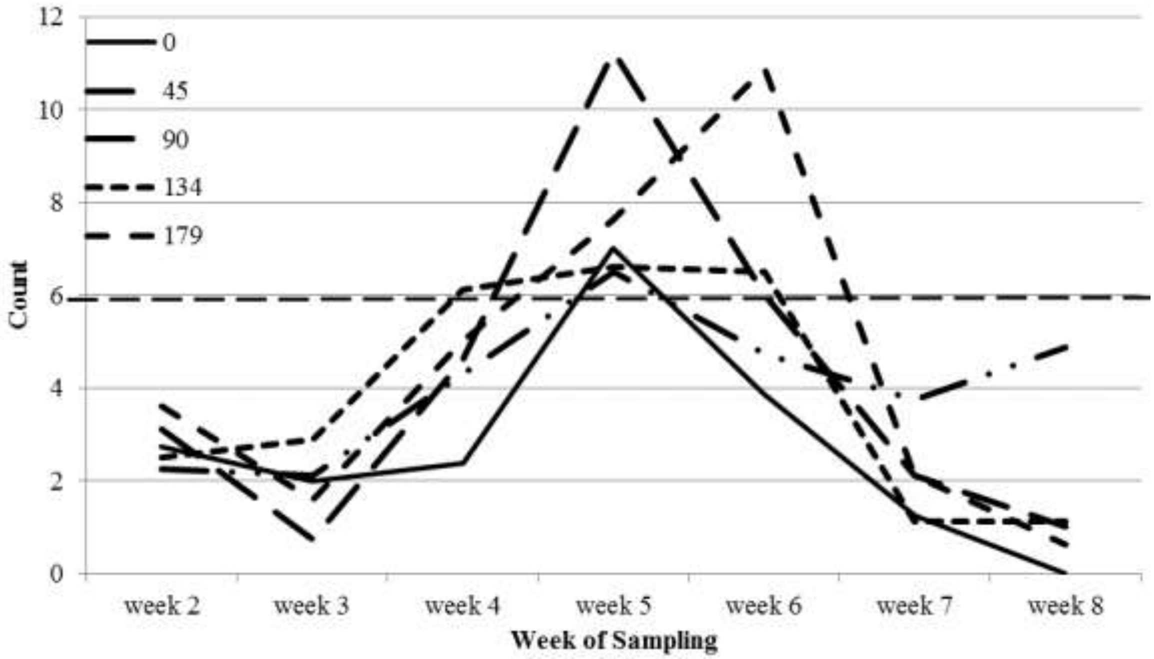

Figure 2.4 Mean densities of *L. Lineolaris* pooled over 2012 and 2013 at each N rate for the sprayed plots.

Densities are expressed as mean number of tarnished plant bugs per week per treatment
Dotted line represents action threshold of six insects in 3 meters of row

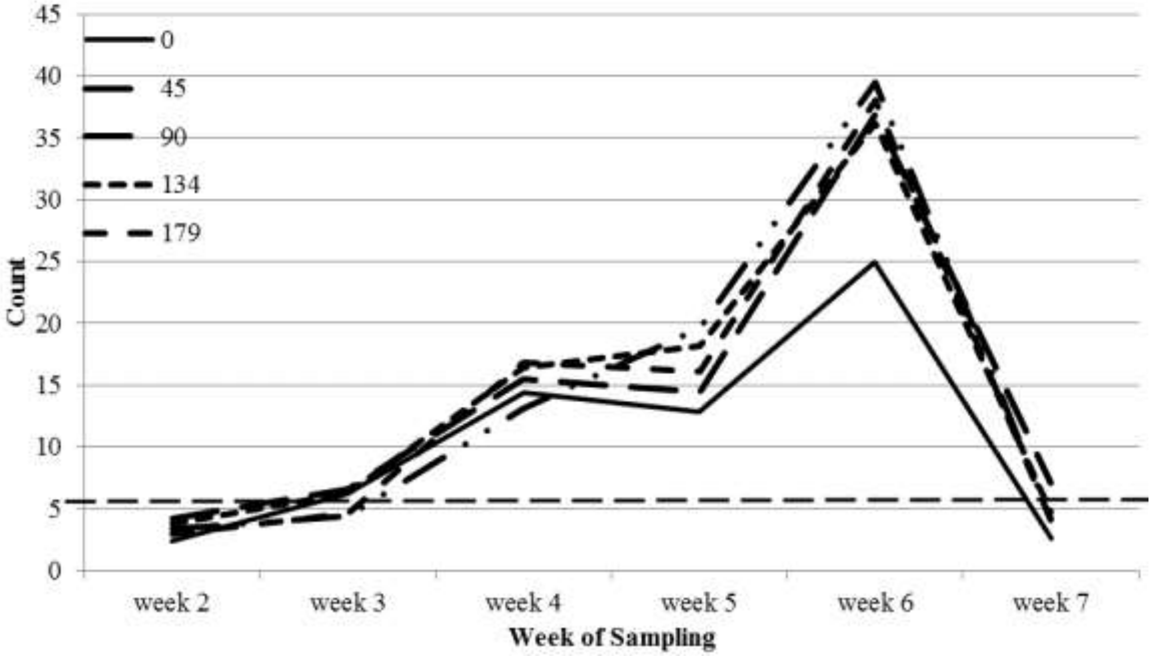

Figure 2.5 Mean densities of *L. Lineolaris* pooled over 2012 and 2013 at each N rate for unsprayed plots.

Densities are expressed as mean number of tarnished plant bugs per week per treatment
Dotted line represents action threshold of six insects in 3 meters of row

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CHAPTER III

DETERMINING OPTIMUM PLANT GROWTH REGULATOR APPLICATION STRATEGIES IN RESPONSE TO FLORAL BUD AND FRUIT REMOVAL

Introduction

Cotton (*Gossypium hirsutum* [L.]) yield is heavily dependent on retention of first position bolls on lower sympodial branches (Mauney, 1984; Jenkins et al., 1990). Regardless of practice used to protect fruiting forms on these positions, they may still abscise due to a multitude of physiological stresses or insect feeding (Guinn, 1982). These stress induced losses may be attributed to reduced carbohydrate supply. (Guinn 1974). However, some fruit loss early in the season is allowable as long as it does not exceed the economic injury level (Bagwell et al., 1999; Parker et al., 1991; Ring and Benedict 1993). The current economic injury level for cotton in Mississippi is 20 percent square loss (Catchot, 2013). However, cotton with square retention of 70 to 85 percent will often produce higher yields than cotton with a higher square retention. Cotton has an indeterminate growth habit, and thus can compensate for fruit lost early in the year; however, the level of compensation depends on agronomic practices and environmental conditions (Cook and Kennedy 2000; Carroll et al., 2012; Dale 1959; Kletter and Wallack 1982; Mann et al., 1997; Ungar et al.,1987). Cotton response to loss of floral buds was defined by Hearn and Room (1979), Kletter and Wallach (1982), and Brook et al., (1992) and further modified by Sadras (1995). The first response is described as being passive and instantaneous. Insect damaged reproductive structures would have shed anyway resulting in no change in the spatial distribution of yield. The second is described as being passive and time dependent. The plant responds by retaining fruiting structures that would have been shed physiologically in order to replace damaged structures. The third response is described as being active and instantaneous. Nutrients that would have been partitioned to damaged structures are partitioned into undamaged structures increasing boll weight in the undamaged structures. The fourth response is described as being an active and time dependent response. Resources that would have partitioned to damaged sites are partitioned into the production of additional fruiting sites thus delaying crop maturity.

Fruit loss results in taller plants as energy devoted to fruit production is re-directed to vegetative growth. However, excessive height can be problematic for pest management, defoliation, and harvest. In addition, it is difficult to manage height of cotton with reduced fruit retention (Hake et al., 1990). Plant growth regulator use has become common in cotton production systems in the United States. The most commonly used plant growth regulator is mepiquat chloride. Applications of mepiquat chloride reduce internode elongation and plant height by reducing gibberellic acid in plant tissues (Nuti et al.; 2006; Reddy et al. 1990; Zhao and Oosterhuis 2000).). Reduced gibberellic acid causes stiffened cell walls and reduced elongation and division of cells (Behringer et al. 1990; Biles and Cothren 2001; Yang et al. 1996).

Yield responses associated with the application of mepiquat chloride have been variable. Some studies suggest yield increase following an application of mepiquat chloride (Cook and Kennedy, 2000; Cathey and Meredith Jr., 1988; Kerby et al., 1998;

Kerby, 1985; Kerby et al., 1983; York, 1983a). Increased yields could be from redistribution of photoassimilates between vegetative and reproductive growth (Nuti et al., 2006). Yield reductions due to mepiquat chloride applications have also been observed (Zhao and Oosterhuis 2000; York 1983a; York 1983b; Cathey and Meredith Jr. 1988). Decreased yields could be from the restricted development of nodes and fruiting sites (Kerby 1985). Dodds et al., (2010) observed no lint yield advantage due to PGR application.

Cook and Kennedy, (2000), found that applications of a plant growth regulator had a positive effect on yield following early bud loss at or greater than that of the economic injury level. Instances where 20 percent of the floral buds were removed followed by four weekly applications of mepiquat chloride at a rate of 12.25 g ha^{-1} yielded significantly greater than treatments with a similar removal rate that received no plant growth regulator, or two bi-weekly applications of mepiquat chloride at 24.5 g ha^{-1}. Cotton with 40 percent floral bud loss receiving two bi-weekly applications of mepiquat chloride at 24.5 g ha^{-1} yielded greater than cotton with similar removal rates that received no plant growth regulator application or received four weekly applications of mepiquat chloride at 12.25 g ha^{-1}. Generally, in the presence of fruit loss, mepiquat chloride application can have a positive effect on yield.

Enhanced earliness has been a claimed benefit from mepiquat chloride application; however, as with yield response to PGR application, contradictory data exits with respect to PGR effect on varietal maturity. Several studies concluded that there is no benefit with respect to enhanced earliness following mepiquat chloride application (Crawford 1981; Stewart et al. 2000; Yeates et al., 2002). However, Kerby et al., (1982) observed increased earliness under conditions favorable for excessive growth or in short season production systems. Wilde et al., (1988) and Kerby et al., (1986) both observed greater retention of early buds and bolls following an application of mepiquat chloride, enhancing the earliness of the crop. Due to the level of variability with respect to cotton response to mepiquat chloride application as well as the lack of data regarding usage rates in the presence of floral bud loss and fruit loss exceeding the economic injury level, a more defined strategy is needed for proper plant growth regulator application where fruit loss has occurred.

Materials and Methods

Studies were conducted in 2012 and 2013 at the R. R. Foil Plant Science Research Center near Starkville, MS and at the Black Belt Branch Experiment Station near Brooksville, MS. Plots were planted on conventionally tilled beds on 18 May 2012 and 15 May 2013 at Starkville, and 19 May 2013 and 20 May 2013 at Brooksville. Plots consisted of four rows spaced 0.96 meters apart that were 12.2 meters in length. At harvest, plots were trimmed to a length of 6.1 meters in length. In 2012, experiments at both locations were conducted under dryland conditions. In 2013, the Starkville location was irrigated and the Brooksville location was dryland. Treatments were arranged in a two-factor factorial arrangement of treatments in a randomized complete block design. Factor A consisted of level of floral bud loss and fruit loss removal. Two levels of removal were used in the study, 50 percent and 100 percent removal of all fruiting structures at first bloom. All fruit were hand removed from a 6.1 m section of each plot located on the center two rows. The 50 percent removal pattern was achieved by using an alternating pattern (Figure 3.1a). The 100 percent removal pattern was achieved by removing every fruiting structure on the plant at first bloom (Figure 3.1b). An untreated (zero removal) check was included for comparison purposes (Figure 3.1c). Factor B consisted of plant growth regulator (PGR) application regimes. The plant growth regulator mepiquat pentaborate (Pentia, BASF Ag Products, Research Triangle Park, North Carolina) was utilized in this experiment. Plant growth regulator application rates consisted of the following: untreated, 0.07 kg ai ha^{-1}, 0.11 kg ai ha^{-1}, 0.17 kg ai ha^{-1}, and 0.22 kg ai ha^{-1}. All PGR application were made immediately after floral bud and fruiting structure removal. Applications were made with a CO_2 powered backpack sprayer using TTI tips. Application pressure was 42 psi and speed was 3 mph. Variety used at both locations for both years was Deltapine 1034 B2RF (mid-maturing) (Monsanto Company, St. Louis, Missouri) at a rate of 13.1 seeds per meter of row. A variety expressing two Bt genes was used in order to minimize impact of lepidopteran pest on final cotton yields. Cotton seed treatment consisted of Acceleron N (thiamethoxam + pyraclostrobin + ipconazole + abamectin) (Monsanto Company, St. Louis, Missouri).

Nitrogen was injected into the soil at 134 kg N ha^{-1} in the form of UAN 32%. Applications were made using a ground driven knife applicator. Fetilizer in the form of P_2O_5 and K_2O were applied at each location based on soil test recommendations. Plots were scouted weekly using appropriate methodology for weed and insect pests with all pesticide and harvest aid applications applied based on Mississippi State University Extension service recommendations.

Data collection included: stand counts 30 days after planting. height, total nodes, and nodes above white flower of cotton prior to fruit removal. In addition cotton height, total nodes, and nodes above cracked boll were collected prior to harvest aid application.

. Nodes above cracked boll was determined by selecting the uppermost first position cracked boll, then counting the number of mainstem nodes between the uppermost first position cracked boll and the uppermost harvestable boll. Defoliation applications were made based on plots receiving 100 perecent of floral bud and fruiting structures removed at first bloom. Yield data were collected using a cotton picker equipped for small plot research. Plots were harvested on 28 October 2012 (Starkville), 31 October 2012 (Brooksville), 18 October 2013 (Starkville), and, 07 November 2013 (Brooksville). 25 boll samples were hand harvested from each plot. Each sample was ginned using a 10 saw Continental Eagle (Lubbock, Texas) laboratory gin. Gin turnout was calculated and 10 grams of lint were sent to Louisiana State University Fiber Quality Laboratory where fiber quality was determined using high volume instrumentation (HVI). All data were analyzed in SAS 9.3 using the PROC GLIMMIX procedure. Means were separated using Fisher's protected LSD ($\alpha \leq 0.05$). Degrees of freedom were calculated using the Kenward – Roger method.

Results and Discussion

Prior to floral bud and fruiting structure removal there were no significant differences in height, total nodes, and nodes above white flower, due to fruit removal being initiated at first bloom. Cotton height averaged 74 cm and 13 nodes prior to fruit removal. Cotton had seven nodes above white flower at the time of removal.

No interaction between fruiting structure and floral bud removal rate and PGR application regime was present for all variables in question. However, fruiting structure and floral bud removal rate and PGR application regime did have a significant effect on plant height at the end of the season (Table 3.1). As removal rate increased, final cotton height significantly increased (Table 3.2). Where 100 percent of fruiting structures and floral buds were hand removed at first bloom, cotton was significantly taller compared to all other treatments. Cotton with 50 percent of all fruiting structures and floral buds removed at first bloom produced significantly taller plants when compared to plots where no removal occurred. (Table 3.2)

Plant growth regulator application rate significantly affected plant height (Table 3.1). Cotton that received no PGR produced significantly taller plants when compared to all other treatments (Table 3.3). No significant differences were present when comparing treatments of 0.17 and 0.22 kg ai ha^{-1} for final plant height. Cotton that received 0.17 and 0.22 kg ai ha^{-1} was significantly shorter compared to all other treatments in question. Mepiquate pentaborate applications of 0.07 and 0.11 kg ai ha^{-1} were significantly shorter than cotton that recieved no PGR application (Table 3.3). These data agree with Dodds et al. (2010) in that regardless of PGR application rate, significant cotton height reductions were observed when compared to the untreated control.

No significant interaction was present between level of floral bud and fruiting structure removal and PGR application rate with respect to total nodes at the end of the season (Table 3.1). However, both level of floral bud and fruiting structure removal and PGR application rate had a significant effect on total nodes at the end of the season. As level of floral bud and fruiting structure removal increased, total nodes significantly increased (Table 3.2). Cotton that had 100 percent of the floral buds and fruiting structures removed at first bloom produced significantly more nodes at the end of the season than all other treatments. Cotton with 50 percent of the fruiting structures and floral buds removed produced significantly more nodes compared to the untreated control

(Table 3.2). However, cotton that had 50% fruiting structure and floral bud loss at first bloom had significantly fewer nodes compared to cotton that had 100 percent of the fruiting and floral structures removed.

Cotton that received no PGR application had significantly more nodes compared to all other treatments. Generally, as PGR application rate increased, the number of nodes decreased. Mepiquat pentaborate application rates between 0.07 and 0.22 kg ai ha^{-1} significantly reduced total nodes at the end of the season compared to the untreated control (Table 3.3). Mepiquat pentaborate applied at 0.22 kg ai ha^{-1} resulted in significantly fewer nodes compared to the untreated control and the 0.07 kg ai ha^{-1} application rate of mepiquat pentaborate (Table 3.3). No significant differences in total nodes at the end of the season were observed following application of mepiquat pentaborate at 0.70, 0.11, and 0.17 kg ai ha^{-1}. Cotton receiving those mepiquat pentaborate application rates produced approximately 20 nodes. All PGR application rates significantly reduced the number of nodes at the end of the season compared to the untreated control.

Individually, level of fruiting structure and floral bud removal and PGR application rate had a significant impact on nodes above cracked boll at the end of the year (Table 3.1). However, there was no significant interaction between the two. Consultants and growers commonly utilize nodes above cracked boll to determine crop maturity and timing of harvest aid application. Nodes above cracked boll were significantly affected by each rate of fruit and floral bud removal (Table 3.2). As level of removal increased, the number of nodes above cracked cracked boll also increased indicating delayed maturity. These data are in agreement with Jones et al., (1996) who also observed a significant delay in maturity in the presence of floral bud removal early in the growing season.

Generally, as PGR application rate increased the number of nodes above cracked boll decreased (Table 3.3). Mean nodes above cracked boll ranged from five to seven nodes with the highest coming from the untreated control (Table 3.3). The lowest number of nodes above the cracked boll was observed in plots receiving mepiquat pentaborate at 2.80 kg ai ha^{-1}. These data agree with Kerby et al., (1982, 1986) and Wilde et al., (1988) who suggest that maturity can be enhanced following PGR application.

Yield was not significantly affected by PGR application (Table 3.1). These data disagree with Cook and Kennedy (2000) who found increased yields where PGR applications were made in the presence of fruiting structure loss. The level of fruiting structures removed by hand at first bloom did have a significant impact on lint yield (Table 3.1). No significant differences with respect to lint yield were observed when comparing cotton that had 50 percent of the fruiting structures removed at first bloom and cotton that had no fruit removed (Table 3.2). Cotton where 100 percent of the fruiting structures were removed at first bloom produced significantly less lint yield when compared to all other treatments. Ungar et al., (1987) suggested that a sufficiently long growing season can be critical for compensation for fruiting and floral structure loss in cotton. Based on this suggestion, the length of growing season during the two years of this experiment was sufficient to allow compensation for up to 50% fruit removal. These data suggest that cotton can compensate for fruit loss greater than the current economic injury level. Although it can compensate for fruit and floral structure loss levels greater than the economic injury level maturity was also delayed. This can be very important following late planting, or years having a wet fall. If floral bud removal had occurred later in the growing season, then compensation would likely be reduced (Ungar et al., 1987, Jones et al., 1996).

The fiber characteristics including length, strength, uniformity, and micronaire were significantly affected by level of fruiting structure removal at first bloom (Table 3.1). Plant growth regulator application had a significant effect on fiber length, strength, and uniformity (Table 3.1). When 100 percent of the fruiting and floral structures were removed at first bloom, fiber length was significantly longer compared to where 50 percent of fruit and floral structures were hand removed at first bloom and no fruit removal (Table 3.4). Although statistical differences were present, based on the CCC Loan Chart (National Cotton Council of America, 2014), differences associated with level of fruit removal at first bloom did not have an economic impact on price received for upland cotton in this study. Cotton fiber length was maximized following a plant growth regulator application of 0.17 kg ai ha^{-1}. Generally, as plant growth regulator application rate increased, fiber length also increased (Table 3.5). Similar to the effects of fruiting structure removal, fiber length differences following increased PGR application rate had no economic impact on price received for upland cotton. Cotton fiber strength significantly increased as level of fruiting and floral bud structure removal at first bloom increased (Table 3.5). The strongest fiber was found in cotton where 100 percent of the fruiting and floral bud structures were removed at first bloom (Table 3.4). However, all treatments had a similar economic impact and would receive a premium based on the CCC Loan chart. Cotton fiber strength was maximized following plant growth regulator application rates of 0.11 kg ai ha^{-1}, and was not different from cotton fiber strength following PGR application rates of 0.17 and 0.22 kg ai ha^{-1} (Table 3.5). Those PGR rates resulted in significantly greater fiber strength than that observed following a mepiquat pentaborate application of 0.07 kg ai ha^{-1} and the untreated control (Table 3.5). Similar to the effects observed with fruiting structure removal, no economic differences were observed with respect to fiber strength due to mepiquat pentaborate application. Cotton fiber uniformity was maximized where 50 percent of the floral and fruiting structures were removed at first bloom and was significantly greater than where no fruiting structures were removed at first bloom (Table 3.4). Where 50 and 100 percent of the floral and fruiting structures were removed at first bloom would have received a 5 point higher point premium due to fiber uniformity compared to the untreated control. Plant growth regulator application rates greater than or equal to 0.11 kg ai ha^{-1} resulted in significantly greater fiber uniformity compared to cotton receiving 0.07 kg ai ha^{-1} of mepiquat pentaborate and the untreated control. Additionally, mepiquat pentaborate applied at these rates resulted in cotton fiber uniformity that would have received a higher premium. Micronaire was significantly lower on cotton where all floral and fruiting structures removed at first bloom when compared to the 50 percent removal rate and the untreated control. However, there was no economic impact associated with those differences.

Conclusion

Both fruit removal and PGR application rate had a significant effect on growth parameters and yield of cotton. Regardless of the level of fruit removal, increasing PGR application rate had a similar effect on cotton height, nodes, and nodes above cracked boll at the end of the season. Generally, as PGR application rates increased cotton height and number of mainstem nodes decreased. Maturity was enhanced following PGR application. Based on these data and previous research, cotton has the potential to compensate for fruiting structure loss greater than that of the current economic injury level employed by several states in the U.S. cotton belt. These data suggest that abandoning a crop in the presence of large level of fruiting loss could be deferred and that the crop could still produce sufficient yield. Although, cotton can compensate for fruit loss it comes at a cost, delayed maturity. This could be very important in years associated with late planting or a wet fall. Results could differ in the event of a high level of fruit loss later in the reproductive stages of cotton. If fruit loss occurred early in the growing season, cotton can potentially compensate for the loss of fruiting structures. PGR applications should be made as needed to manage vegetative growth of the plant. In the presence of fruit loss, PGR applications $\geq$ 1.40kg ai ha^{-1}may result in greater premiums associated with fiber quality.

Table 3.1 Analysis of variance and associated P values for removal rate and mepiquat pentaborate rate effects on growth and development of cotton, lint yield, fiber length, fiber strength, fiber uniformity, and micronaire of cotton grown in 2012 and 2013.

Effect	D.F.[D]	1st Bloom Height	1st Bloom Nodes	NAWF[A]	EOS[B] Height	EOS Nodes	NACB[C]	Lint Yield	Fiber Length	Fiber Strength	Fiber Uniformity	Micronaire
		---P values---										
Removal Rate	2	0.99	0.48	0.87	<0.0001	<0.0001	<0.0001	0.04	0.0002	<0.0001	0.0001	0.016
PGR[E] rate	4	0.65	0.60	0.89	<0.0001	<0.0001	0.0008	0.18	<0.0001	<0.0001	<0.0001	0.74
Removal Rate *PGR rate	8	0.97	0.93	0.95	0.61	0.45	0.78	0.37	0.64	0.41	0.7688	0.75

[A] Nodes above white flower
[B] End of season
[C] Nodes above cracked boll
[D] Degrees of Freedom
[E] Mepiquat pentaborate

Table 3.2 Effect of fruit and floral bud structure removal on growth and development of cotton at the end of the season across locations, years, and mepiquat pentaborate application rate.

Fruit Removed At 1st bloom	Final Height	Final Nodes	NACB^A	Lint Yield
-----%-----	-----cm-----	-----#-----	-----#-----	-----kg lint ha^{-1}-----
0	112 c	19 c	5 c	2001 a
50	117 b	20 b	6 b	1998 a
100	127 a	21 a	7 a	1872 b

Means within a column followed by the same letter are not significantly difference at ($\alpha \leq 0.05$)

^{A} Nodes above cracked boll

Table 3.3 Effect of plant growth regulator application rate on growth and development of cotton at the end of the season across locations, years, and fruit removal rate

PGR Application Rate	Final Plant Height	Final Nodes	NACB^A
-----kg ai ha^{-1}-----	-----cm-----	-----#-----	-----#-----
0	136 a	21 a	7 a
0.70	119 b	20 b	6 b
1.40	117 b	20 b	6 b
2.10	112 c	20 b	6 b
2.80	109 c	19 c	5 c

Means within a column followed by the same letter are not significantly different at ($\alpha \leq 0.05$)

^{A} Nodes above cracked boll

Table 3.4 Effect of fruit removal on fiber characteristics of cotton across locations, years, and mepiquat pentaborate application rate.

Fruit Removed At 1st bloom	Fiber Length	Fiber Strength	Fiber Uniformity	Micronaire
-----%-----	-----cm-----	-----g tx^{-1}-----	-----%-----	
0	2.98 b	31.37 c	83.86 b	4.63 a
50	2.98 b	31.80 b	84.14 a	4.62 a
100	3.01 a	32.27 a	84.34 a	4.51 b

Means within a column followed by the same letter are not significantly difference at ($\alpha \leq 0.05$)

Table 3.5 Effect of plant growth regulator application rate on fiber characteristics of cotton grown across locations, years, and fruit removal rate.

PGR Application Rate	Fiber Length	Fiber Strength	Fiber Uniformity
-----kg ai ha^{-1}-----	-----cm-----	-----g tx^{-1}-----	-----%-----
0	2.95 d	31.27 b	83.77 c
0.70	2.98 c	31.49 b	83.95 bc
1.40	2.99 bc	31.95 a	84.19 ab
2.10	3.01 ab	32.08 a	84.26 a
2.80	3.01 a	32.28 a	84.41 a

Means within a column followed by the same letter are not significantly different at ($\alpha \leq 0.05$).

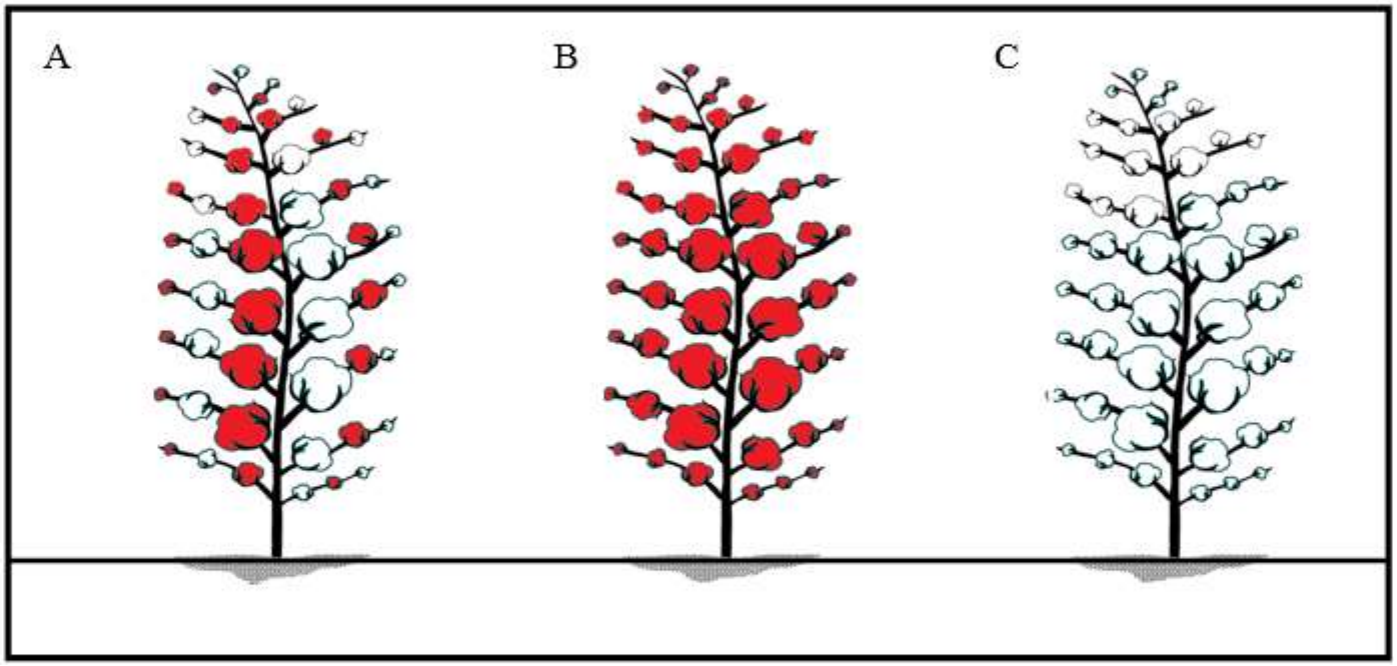

Figure 3.1 Fruit removal patterns at first bloom in 2012 and 2013. Red indicates a structure that would be removed

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CHAPTER IV

THE EFFECTS OF NITROGEN APPLICATION RATE AND PLANT POPULATION ON COTTON GROWTH, DEVELOPMENT, YIELD AND FIBER QUALITY

Introduction

Seed premiums, technology fees associated with transgenic technology, and the use of seed treatments have increased at–planting costs for cotton and have caused renewed interest in reduced plant populations (Siebert and Stewart 2006). Cotton is planted in a variety of row configurations and plant populations. However, the overall establishment of an acceptable population in cotton is critical in obtaining high yield (Christiansen and Rowland 1981). An acceptable plant population varies by location, environment, cultivar, and grower preferences (Silvertooth et al., 1999). Previous research indicates that maximum cotton yields in the Mississippi Delta were obtained with a population range between 7.0-12.1 plants m^{-2}. Fowler and Ray (1977) suggested that the optimum plant populations for cotton in Texas were between 7.9-15.5 plant m^{-2}. In addition, Hicks et al. (1989) found optimum plant populations for Texas were between 7.0-14.0 plants m^{-2}.

Siebert and Stewart (2006) compared cotton yields with a variety of different plant densities and seeding configurations. Results were inconsistent from year to year and were heavily influenced by environmental conditions. Bridge et al. (1973) and York (1983) found that higher plant populations tended to result in taller plants. Furthermore, increased plant populations also resulted in a reduction in the number of mainstem nodes (Buxton et al., 1977; Kerby et al., 1990a; Kerby et al., 1990b; Galanopoulou-Sendouka et al., 1980; Heitholt 1995; Jones and Wells 1997; Siebert and Stewart., 2006; Wanjura and Bilbro Jr. 1977).

Lower plant populations may also delay maturity (Siebert and Stewart, 2006). Delayed maturity was likely caused by more bolls on monopodial branches, more distal sympodial fruiting positions on sympodial branches, more late-season flowers, and greater retention in these fruiting areas. Galanopoulou-Sendouka et al. (1980) and Guin et al. (1981) observed a 2.25-fold increase in total bolls per plant at lower plant densities. Bednarz et al., (2000) found that yield from cotton grown at lower densities was achieved through supplemental fruiting site production.

Boll weights have an inverse relationship to population density (Bednarz et al., 2000). First and second position boll weights on sympodial branches were more heavily influenced by the main stem node they were located on as opposed to plant population density. However, third position sympodial bolls were influenced more so by plant population density than the mainstem node they were located on. Distal fruiting sites were also influenced by plant population densities as higher plant populations reduced the overall number of distal fruiting sites due to interplant competition (Bednarz et al., 2000).

Bednarz et al. (2000) found that lower population densities in cotton lead to increased number of fruiting sites and heavier fruit. As plant populations increase, the number of fruiting sites, total fruit load, and boll weight decrease. Jones and Wells (1998) found no differences in cotton yield due to reduced plant density. This is due in part to an increased number of main stem nodes and distally located sympodial and monopodial bolls on plants grown in lower plant densities (Jones and Wells 1997; Siebert and Stewart, 2006). Siebert and Stewart (2006) also suggest that lower plant densities can decrease plant height to node ratios.

Efficient N nutrition of cotton is critical not only for successful production, but also to minimize environmental impacts (McConnell et al., 2008). Nitrogen fertilizer is used on over 90 % of the cotton acres in the U.S. to optimize growth and profit (Fertilizer Inst. 1998). Mississippi State University Enterprise budgets suggest that the average cost per hectare for N fertilizer (UAN 32%) in a convential tillage system in the Mississippi Delta area is $183.18 (Mississippi State University 2013). In 2007, an average of 131 kg N ha^{-1} was applied (NASS 2007). Nitrogen is commonly applied every year due to its movement throughout the soil and its use by the plant. Nitrogen is a key element in the growth and maturity of a cotton crop. Cotton yield potential is strongly influenced by nitrogen availability (Clawson et al., 2006). In dryland and irrigated cotton production systems; N has the greatest impact on lint yield, earliness, and lint quality when compared to all other nutrients (Hutmacher et al., 2004). In addition, the amount of N utilized can change the overall architecture of the cotton plant (Clawson et al., 2006). Nitrogen levels vary across a given field due to the amount of N removed by a crop during the growing cycle as well as through volatilization, denitrification, leaching, and runoff (Mallarino and Wittry 2004).

Clawson et al. (2008) found that nitrogen application rate did not impact harvest timing of ultra- narrow row cotton; however, increased N application rates did increase lint yields. Increased N application rates also resulted in a delayed crop maturity. Reduced N application rates reduced the percentage of total bolls located on upper nodes.

Jackson and Gerik (1990) found that when N is deficient there is a reduction in main stem nodes. Furthermore, Clawson et al. (2006) found that when N was applied, the weight of individual bolls was greatly increased, and that the overall boll weight across all sympodial branches was increased. Other data suggest that N fertilizer did not affect yield (Stevens et al., 1996). In those studies the crop was under drought stress during boll set and boll fill and residual and mineralized N fulfilled plant needs. The applied N had either been absorbed, or leached resulting in minimal effects due to N application.

Crop rotation must also be considered when determining N application rates for cotton. When cotton is rotated with corn, increases in yield have been shown with lower N application rates (Boquet et al., 2009). Boquet et al. (2009) also indicated that in cotton-corn rotations where 224 to 280 kg N ha^{-1} was applied to the corn, reduced N application rates in cotton resulted in optimum yields.

Growers have been progressively reducing seeding rates as seed and technology fees have increased over the past 15 years. However, Mississippi State University Extension Service soil testing recommendations for N application rates in cotton production have remained unchanged. Research is needed to determine if N application rates should be adjusted to account for the reduction in seeding rates and resultant plant populations.

Materials and Methods

Experiments were conducted in 2012 and 2013 to determine the effect of plant population and N application rate on cotton growth, development, and yield. Experiments were established in 2012 at the Black Belt Branch Experiment Station (Brooksville 2012 and Brooksville 2013.) and the R. R. Foil Plant Science Research Facility (Starkville

2012 and Starkville 2013). Studies were conducted in 2012 and 2013 on a Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts) in Starkville and a Brooksville silty clay(fine, smectitic, thermic Aquic Hapluderts) in Brooksville. Studies conducted at the R. R. Foil Plant Science Research Facility location were furrow irrigated; whereas, experiments at the Black Belt Branch Experiment Station were grown under dryland conditions. At all locations and years, cotton was the previous crop. Cotton plant population and N application rate treatments were placed in the same locations and same randomizations for the both years of this experiment.

The entire experiment area was marked using flags at each corner, as well as to mark alleys. Corners were also marked using a handheld GPS with sub meter accuracy to verify accurate plot placement between years. Fertilizer N was applied in the form of urea ammonia nitrate (UAN) 32% liquid by a tractor mounted, ground-driven liquid N applicator at pinhead square. All N was applied in a single application. Experiments were conducted using a factorial arrangement of treatments in a randomized complete block design. Factor A consisted of N rate and included the following: 0 (untreated), 45, 90, 134, 179 kg N ha^{-1}. Factor B consisted of plant population and included the following: 37,050; 74,100; 111,150; and 148,200 plants ha^{-1}. Once full cotton emergence had occurred, plant densities were determined, and populations were hand thinned to the aforementioned plant populations. Each treatment was replicated four times. Treatment means were calculated across replicates for each year at each location. There were four site-years for N-rate and plant population. Each measurement was initially regressed on N-rate and plant population allowing for both linear and quadratic terms with coefficients depending on N-rate, plant population, year, and location. Insignificant ($P \leq 0.05$) model terms were removed sequentially and the model was refit until a satisfactory model was obtained. All statistical analyses were conducted using SAS version 9.3. (SAS Institute Inc., Cary NC)

The cotton cultivar Deltapine 0912 B2RF was planted into conventionally tilled seed beds on 18 May 2012 at Starkville and 19 May 2012 at Brooksville. Cotton was planted on 15 May 2013 for the Starkville location, and 20 May 2013 for the Brooksville location. Cotton was planted using a ground driven John Deere planter equipped with Max Emerge XP planting units. A cultivar expressing two Bt genes and was utilized to minimize impact of lepidopteran pests on final cotton yields. Seed were also treated with a commercial premix of thiamethoxam, pyraclostrobin, fludioxonil, mefenoxam, myclobutanil, and TCMTB (Monsanto Company, St. Louis, Missouri). Plots consisted of four 96 cm rows that were 12.2 m in length. Cotton weed and insect management, as well as irrigation management at Starkville, was performed based on Mississippi State University Extension Service recommendations.

In season data were collected at two different time periods. Data at first flower included: height (cm), node count, and nodes above white flower (NAWF). Nodes above white flower were evaluated by locating the uppermost first position white flower then counting upward to the apical meristem. End of season data were collected one week prior harvest aid application. Data included final height (cm), final node count, first fruiting branch (FFB), node of uppermost harvestable boll, and nodes above cracked boll. Nodes above cracked boll were determined by locating the uppermost first position cracked boll and counting the nodes to the uppermost harvestable boll.

Plots were harvested on 28 October 2012 and 18 October 2013 at Starkville. Plots at Brooksville were harvested on 31 October 2012 and 07 November 2013. Seed cotton yield was determined at physiological maturity by harvesting the center two rows of each plot with a spindle type picker set up for small plot research. Weights were recorded and yields were adjusted to kg ha^{-1}. Twenty-five boll samples were hand harvested from each plot. Each sample was then ginned using a 10 saw Continental Eagle (Lubbock, Texas) laboratory gin. Gin turnout were calculated and 10 grams of lint were sent to Louisiana State University Fiber Quality Laboratory where fiber quality was determined using high volume instrumentation (HVI).

Results and Discussion

Cotton height was significantly affected by N rate (Table 4.1). Cotton height at first bloom was also significantly affected by plant population (Table 4.2). However, there was no interaction between the two on cotton height at first bloom. Cotton height at first bloom in Brooksville in 2012 and 2013 decreased non-linearly as N rate (kg N ha^{-1}) increased (Table 4.3). Generally, as cotton plant population increased, cotton plant height decreased. Cotton height in Starkville in 2012 and 2013 responded nonlinearly (quadratic) as N rate increased. Intercepts varied in 2012 for the Starkville location and had no set pattern. These results could potentially be associated with excess N present in the field from previous research. In 2013, as plant population increased, cotton height decreased. Population, year, and location all played a significant role in the trend by which height was affected. Three of the four models plant height decreased significantly in a linear manner as plant population decreased (Table 4.4). The only insignificant model was from the Starkville location in 2012. As previously stated, this could be attributed to a high level of residual N being present at the Starkville location prior to the initiation of the experiment. Cotton height at first bloom at the Starkville location was significantly reduced by a rate of 0.7 cm per every 10,000 plants ha^{-1} increase in plant population (Table 4.4). At the Brooksville location, cotton height at first bloom was significantly decreased by a rate of 0.5 cm per 10,000 plants ha^{-1} increase in plant population (Table 4.4). These data disagree with Bridge et al. (1973) and York (1983) who found that higher plant populations tended to result in taller plants. These data suggest plant population could affect early season plant height in an inverse manner.

Cotton nodes at Brooksville and Starkville in 2012 and 2013 were unaffected by N rate (Table 4.1). Cotton nodes at both locations in both years were significantly affected by a three way interaction of population, year, and location in a linear trend (Table 4.2). Generally, across all years and locations as plant population increased, the number of nodes decreased. In 2012 and 2013, cotton nodes at Brooksville decreased at a rate of 0.1 nodes per 10,000 plants ha^{-1} increase in plant population. Reduction in cotton nodes in Starkville differed between years. In 2012, for every 10,000 plants ha^{-1} increase in cotton plant population, the number of nodes at first bloom per plant significantly decreased by 0.06 nodes. In 2013, for every 10,000 plants ha^{-1} increase in plant population the number of nodes decreased by 0.2. Intercepts also differed between years at the Starkville location. These differences could be associated with excess residual N in 2012 (Figure 4.1). These data suggest that the number of nodes early in the season is more dependent on plant population rather than N rate.

Cotton nodes above white flower (NAWF) produced in 2012 and 2013 were affected by N rate and were described as a linear trend at both locations (Table 4.1).

Location did not have a significant impact on the trend; however, it was observed to differ among years. A significant linear increasing trend was observed for cotton grown in 2013 with respect to NAWF (Table 4.6) As N rate increased, NAWF increased significantly at a rate of 0.002 per unit (kg N ha^{-1}) increase in N rate. Intercepts differed among plant populations ranging from 7.7 NAWF at a plant population of 37,050 (plants ha^{-1}) to 6.4 at a plant population of 148,200 (plants ha^{-1}). Cotton plant population, year, and location all had a significant effect on NAWF. Reductions in NAWF differed among locations and years. Cotton NAWF in Brooksville in 2012 decreased linearly at a rate of 0.082 NAWF per 10,000 plants ha^{-1} increase (Table 4.7). In 2013, cotton grown at both locations was significantly affected by plant population (plants ha^{-1}). Cotton NAWF at both locations was significantly reduced at a level of 0.100 NAWF per 10,000 plants per ha^{-1} increase in plant population. Differences in NAWF between locations were observed. Cotton grown at Brooksville averaged 8.7 NAWF across all N rate treatments; whereas cotton grown at Starkville averaged 7.8 NAWF across all N rate treatments (Table 4.7).

Cotton height at the end of the season was significantly affected by N rate and differed by year and location and followed a linear trend (Table 4.1). Cotton height at Brooksville in 2012 significantly increased at a rate of 0.076 cm per unit increase in N rate (kg N ha^{-1}) when averaged across all plant populations (Table 4.8). Furthermore, in 2013 a similar trend was observed for cotton grown at Brooksville. Across all populations, cotton heights increased at a rate of 0.066 cm per unit increase in N rate (kg N ha^{-1}) (Table 4.8). There was no trend for cotton height in 2012 at Starkville. This could be related to excessive residual N from previous years. Cotton height in 2013 at the Starkville location significantly increased at a rate of 0.079 cm per unit increase of N rate (kg N ha^{-1}). Data from Brooksville in 2012 and both locations in 2013 agrees with Main et al. (2013) who observed a significant increase in plant height as N rate increased. In 2012 there was no general trend observed with respect to plant population effect on cotton height at the end of the season (Table 4.2). Generally, as plant population increased in 2013 at Starkville, mean cotton height at the end of the season also increased. This suggests that cotton height can be significantly affected by plant population in some situations. Cotton height in 2012 and 2013 at Brooksville significantly decreased in a linear fashion at a rate of 0.7 cm with every 10,000 plant ha^{-1} increase in plant population (Table 4.9). No differences in cotton height at the end of the season were observed due to plant population at the Starkville location in 2012 (Table 4.9). However, cotton plant height at the end of the season was significantly reduced by a rate of 1.1 cm per every 10,000 plants ha^{-1} increase in plant population in 2013. Data from Brooksville 2012, 2013, and Starkville 2013 disagrees with Bridge et al., (1973) and York (1983) who found that higher plant populations resulted in taller plants.

Nitrogen application rate had a significant effect on mainstem cotton nodes at the end of the season (Table 4.1). Increased nodes at the end of the season varied by year and location. In 2012, cotton nodes at Brooksville increased at a rate of 0.01632 nodes per each additional unit (kg N ha^{-1}) applied (Table 4.10). A similar linear trend was observed in 2013. However, for every unit of increase in N application rate (kg N ha^{-1}), cotton node counts increased by 0.012 nodes per plant. Cotton nodes in 2012 at Starkville significantly increased at a rate of 0.009 nodes per each additional kg of N ha^{-1}. Increased in node counts were also observed for cotton grown in Starkville in 2013. Node counts trended upward at a rate of 0.015 per each additional kg of N ha^{-1}(Figure 4.2).

Differences in node counts over years could be related to environmental conditions and N availability. These data agree with Main et al. (2013) and Clawson et al. (2008) who found that as N rate increased, the plant architecture also changed. Main et al. (2013) observed that residual residual N existed, and based on changes in the level of increase at both locations this could potentially contribute to the effects observed in 2012.

A significant linear trend was present when comparing total nodes at the end of the season to plant population (Table 4.2). Results varied by location and N rate (kg N ha^{-1}) (Table 4.11). At both locations with each additional plant added per hectare, the number of nodes significantly decreased with the exception of plant populations which received 179 kg N ha^{-1} (Table 4.11). Results from Brooksville and Starkville would indicate plant populations cause a reduction in the number of mainstem nodes (Buxton et al., 1977; Kerby et al., 1990a; Kerby et al., 1990b; Galanopoulou-Sendouka et al., 1980; Henholt 1995; Jones and Wells 1997; Siebert and Stewart, 2006; Wanjura and Bilbro Jr. 1977). However, no significant decrease was observed as plant population increased following high levels of applied N.

Cotton nodes above cracked boll (NACB) were affected by N rate (Table 4.1). The trend was defined as linear for all years and locations; however, the level of increase varied by year and location. Cotton NACB in Brooksville in 2012 increased significantly at a rate of 0.018 NACB with each addition kg N ha^{-1} applied (Table 4.12). Cotton NACB in Brooksville in 2013 significantly increased at a rate of 0.013 nodes per unit increase of N applied. Cotton grown in Starkville followed a similar trend; however, the level of change observed due to additional kg N ha^{-1} varied by year. Cotton NACB in 2012 significantly increased at a rate of 0.013 NACB with each addition kg N $^{-1}$. Cotton grown in 2013 had a greater response to additional N when compared to cotton grown in 2012 at the Starkville location (Figure 4.3). Cotton NACB in 2013 significantly increased at a rate of 0.017 NACB per unit increase of N. These data agree with Clawson et al. (2008) and Main et al. (2013) who found that increased N availability caused NACB to increase, which indicates delayed maturity. Due to an ever changing weather pattern across much of the cotton belt, delayed in maturity can have a negative impact on cotton yield. This may lead to the crop being in field longer, which could potentially lead to increased pesticide applications, as well as reduced efficiency of a producer's operation.

A significant trend was also established for the relationship of node of uppermost harvestable boll (NUHB) and N rate (kg N ha^{-1}) (Table 4.1). Regardless of year, location, or plant population, as each addition kg N ha^{-1} was applied, NUHB significantly increased at a rate of 0.133 NUHB (Table 4.13). The r^2 values associated with this trend increased the following year for both locations (Figure's 4.4-4.7). Larger differences in this value were associated with the Starkville location. As plant population increased, NUHB boll decreased. In addition, a linear trend was observed between plant population (plants ha^{-1}) and NUHB of cotton grown in Brooksville and Starkville in 2012 and 2013 (Table 4.2). Reductions varied by year and location. Mean NUHB was observed to decrease as cotton plant population increased. Cotton NUHB in Brooksville in 2012 significantly decreased at a rate of 0.3 nodes per each addition 10,000 plants ha^{-1} added to the population. Mean NUHB of cotton grown in 2013 at Brooksville significantly decreased at a rate of 0.1 nodes per 10,000 plants ha^{-1} added to the plant population (Table 4.14). Change in cotton NUHB in Starkville in 2012 was observed to be insignificant (Table 4.14). However, in 2013 following each additional 10,000 plants ha^{-1}

increase in plant population, a significant decrease in NUHB of 0.2,was observed for cotton grown in Starkville. As N rate increased, and plant population decreased, NUHB moved upward in the plant canopy. If N rate is decreased, and plant population is increased NUHB moved downward in the plant canopy.

A significant linear trend was found when comparing gin turnout and N rate (kg N ha^{-1}) (Table 4.1). The trend differed by year and location. In 2012, cotton gin turnout from Brooksville significantly decreased at a rate of 0.00004 percent with each addition kg N ha^{-1} applied(Table 4.15). Cotton gin turnout from Starkville in 2013 followed a similar trend in that as N rate increased gin turnout decreased on a linear basis. However, the level of reduction was less than that observed in 2012 in Brooksville. Gin turnout for cotton grown in Starkville significantly decreased at a level of 0.00012 percent with each addition kg N ha^{-1} applied. Differences among years could be attributed to differences in environmental conditions.

A nonlinear (quadratic) trend was observed for the relationship between lint yield and N rate (Table 4.1).Cotton lint yield at both locations in 2012 and 2013 varied in response to applied N. The effect of N application rate was observed to be linear in 2012 at the Brooksville location (Table 4.1) with each additional increase in kg N ha^{-1} lint yield increased (Table 4.16). Across all plant populations, the average increase in lint yield was 4.82 kg lint ha^{-1} with each addition kg N ha^{-1} applied (Table 4.16) (Figure 4.8). In 2013, cotton lint yield at Brooksville was described as a nonlinear (quadratic) trend in which absolute agronomic yield peaking at 166 kg N ha^{-1} across all populations (Figure 4.8). Cotton lint yield from Starkville in 2012 was described as a linear trend. Lint yield of cotton grown in Starkville in 2012 increased a rate of 3.67 kg lint ha^{-1} with each addition kg N ha^{-1} applied. Cotton lint yield from 2013 at Starkville was observed to follow a significant nonlinear (quadratic) trend (Figure 4.8). However, yield was predicted to be maximized outside of the treatments used in testing; therefore predictions attained were not valid. Results differed from Main et al. 2013. This could be due to the constant turnover of N during reactions, denitrification, mineralization, as well as immobilization associated with soil types used in this experiment. These processes depend on the C/N ratio relative to the soil, and all could differ based on soil type (Bohn et al., 1985). Differences among locations in 2013 could be attributed to the Brooksville site being a dryland environment whereas the Starkville site was furrow irrigated.

A significant trend was present between lint yield (kg lint ha^{-1}) and plant population (plants ha^{-1}). Although the trend was present, only minimal differences were associated with changes in yield compared to changes in the plant population. In only two instances in 2013 was the change in yield observed to be significant (Table 4.17). These data agree with Jones and Wells (1998) who also observed no differences in cotton yield due to a reduction in plant density. This is due in part to an increased number of main stem nodes and distally located sympodial and monopodial bolls on plants grown in lower plant densities (Jones and Wells 1997; Siebert and Stewart, 2006).

Cotton fiber length (cm) and fiber strength (g tex^{-1}) were significantly affected by N rate (kg N ha^{-1}) and varied by year and location (Table 4.18). Cotton fiber length from 2012 at the Brooksville location generally increased as N rate increased. Cotton that received 179 kg N ha^{-1} at Brooksville in 2012 produced significantly longer fiber than any other N application rate treatment. Cotton fiber length in 2013 at Brooksville was statistically maximized in plots receiving 90 kg N ha^{-1}. However, fiber length for cotton receiving 90 kg N ha^{-1} was not significantly different from cotton fiber length following applications of 134 and 179 kg N ha^{-1} (Table 4.18). Cotton grown in 2012 at the Starkville location was observed to have similar results to that of cotton grown in Brooksville in 2013. Plots receiving N rates ≥90 kg N ha^{-1} produced cotton with significantly longer fiber than that of cotton receiving no N (Table 4.18). Cotton fiber length from 2013 at Starkville differed in that as N rate increased, fiber length also increased. Cotton receiving 179 kg N ha^{-1} produced significantly longer fiber length than that of cotton receiving 90, 45, and 0 kg N ha^{-1}. However, no significant differences were observed for cotton fiber length following applications of 179 kg N ha^{-1} and 134 kg N ha^{-1}, respectively. These results agree with Bauer and Roof (2004) who observed that cotton grown in the absence of N produced fiber shorter than that of cotton where N was applied. Cotton fiber strength (g tex^{-1}) from 2012 at the Brooksville location increased when N was applied compared to cotton grown in plots receiving no N application. Cotton receiving 179 kg N ha^{-1}produced cotton fiber with significantly more strength (g tex^{-1}) than that of cotton to which 90 and 0 kg N ha^{-1} were applied. There were no significant differences observed in 2013 in cotton fiber strength from Brooksville in response to varying N rates and fiber strength ranged from 29.6-30.2. Similarly, no differences were observed with respect to fiber strength from cotton grown in 2012 at the Starkville location and fiber strength ranged from 30.8 to 30.3 g tex^{-1}. Cotton fiber strength from 2013 at Starkville was significantly affected by N rate. Fiber strength increased with each increase in N rate. Cotton fiber strength from 2013 at the Starkville location was maximized in plots receiving 45 kg N ha^{-1}. Cotton fiber strength from 2012 in Brooksville and 2013 in Starkville would agree with Bauer and Roof (2004) who observed that cotton fiber strength in the absence of N was weaker than of cotton grown in the presence of N.

Cotton fiber uniformity was significantly affected by N rate (kg N ha^{-1}) regardless of year or location. As N rate increased uniformity also increased. Cotton that received 134 and 179 kg N ha^{-1} had significantly greater fiber uniformity compared to cotton that received no N(Table 4.19). These results agree with Bauer and Roof; (2004) who observed that length uniformity significantly declined in the absence of N.

Cotton micronaire differed by year among locations. In both 2012 and 2013, cotton grown in Starkville was observed to have higher micronaire than that of cotton grown in Brooksville. The variety used in this study has the ability to produce a micronaire value high enough to affect market price of cotton (rating ≤5.0). In 2012, cotton grown in Starkville had a micronaire value significantly greater than cotton grown in Brooksville and price reductions could follow based on this value. In 2013, cotton grown in Brooksville was observed to have significantly lower micronaire when compared to the Starkville location (Table 4.20). However, both values were above 5.0 which would lead to a reduction in price. Differences among locations could be associated with difference among environmental conditions. Cotton grown in Brooksville was grown under dryland conditions whereas cotton grown in Starkville received supplemental irrigation.

Conclusion

Nitrogen application rate (kg N ha^{-1}) and plant population had significant impact on cotton growth and development throughout the growing season (Table 4.1 & 4.2). As N rate increased cotton NAWF, plant height at the end of the season, mainstem nodes at the end of the season, NACB, NUHB, and lint yield in 2012 increased linearly. The effect of N rate at the end of the season on height, nodes, and NACB agree with Main et al. (2013) However, as plant population increased height at first bloom, nodes at first bloom, NAWF, end of season heights, end of season nodes, and NUHB significantly decreased at both locations. The effect of plant population on plant height in this study generally disagreed with Bridge et al., (1973) and York (1983) who observed increased height in higher plant populations. Lint yield varied by year and location. Lint yield of cotton grown in 2012 at Brooksville was observed to increase linearly with each additional increase in N applied. There was a significant linear effect associated with cotton lint yield grown in Starkville in 2012.Cotton yield in both locations in 2013 was observed to follow a nonlinear (quadratic trend). However, predicted lint yields were not valid for the Starkville location due to maximum agronomic yield falling outside of nitrogen application rates tested. Cotton lint yield from Brooksville in 2013 was maximized at N application rates of 166 kg N ha^{-1}. These variations could potentially be associated with soil texture differences, environmental conditions, and the constant turnover of nitrogen during denitrification, mineralization, and immobilization. Gin turnout was also heavily influenced by N rate; however, trends differed among years. Fiber length, strength, and uniformity were all affected by N rate. However, the effects of N on fiber length and strength measurements varied by years and locations. Micronaire was not affected by N rate or plant population, but differed by location which could be attributed to environmental conditions.

Table 4.1 Analysis of variance p-values for first bloom heights, first bloom nodes, first bloom NAWF[a], final heights, final nodes, first fruiting branch, NACB[b], node of uppermost harvestable boll, gin turnout, and lint yields as affect by N rate (kg N ha^{-1}).

Source	D.F.[c]	First Bloom HT[d]	First Bloom ND[e]	First Bloom NAWF	Final HT	Final ND	FFB[f]	NACB	NUHB[g]	Turnout	LT[h] Yield
Year	1	<0.0001	<0.0001	0.0006	<0.0001	<0.0001	<0.0001	--	<0.0001	--	<0.0001
Location	1	<0.0001	0.0015	--	<0.0001	0.0215	--	--	0.0141	<0.0001	<0.0001
Year x Location	4	<0.0001	<0.0001	0.0065	<0.0001	<0.0001	--	<0.0001	0.0004	0.0436	<0.0001
Population	3	<0.0001	0.0005	<0.0001	--	<0.0001	0.0432	-	<0.0001	--	--
Year x Population	8	0.0013	--	0.0008	--	--	--	--	--	--	--
Location x Population	3	--	--	--	--	--	--	--	--	--	--
Year x Location x Population	3 or 16	0.0082	--	--	0.0393	--	--	--	0.0329	--	--
Linear N-rate	1	--	--	--	--	--	--	--	<0.0001	--	--
Linear N-rate x Year	1	--	--	0.0338	--	--	--	--	--	--	--
Linear N-rate x Location	2	0.0079	--	--	--	--	--	--	--	--	--

Table 4.1(Continued)

Linear N-rate x pop[h]	3	--	--	--	--	--	--	--	--	--	--
Linear N-rate x year x population	3	--	--	--	--	--	--	--	--	--	--
Linear N-rate x location x pop	3	--	--	--	--	--	--	--	--	--	--
Linear N-rate x year x location	4	--	--	--	<0.0001	<0.0001	--	<0.0001	--	<0.0001	<0.0001
Linear N-rate x location x year x pop	3	--	--	--	--	--	--	--	--	--	--
Quadratic N-rate x N-rate	1	--	--	--	--	--	--	--	--	--	--
Quadratic N-rate x N-rate x year	2	--	--	--	--	--	--	--	--	--	<0.0001
Quadratic N-rate x N-rate x location	2	0.0497	--	--	--	--	--	--	--	--	--
Quadratic N-rate x N-rate x pop	3	--	--	--	--	--	--	--	--	--	--

Table 4.1 (Continued)

Quadratic N-rate x N-rate x year x pop	3	--	--	--	--	--	`--	--	--	--	--
Quadratic N-rate x N-rate x pop x location	1	--	--	--	--	--	--	--	--	--	--
Quadratic N-rate x N-rate x year x location	3	--	--	--	--	--	--	--	--	--	--
Quadratic N-rate x Quadratic N-rate x year x location x pop	3	--	--	--	--	--	--	--	--	--	--

[a] Abbreviation: Nodes above white flower

[b] Abbreviation: Nodes above cracked boll

[c] Degrees of Freedom

[d] Abbreviation: Height

[e] Abbreviation: Nodes

[f] Abbreviation: First fruiting branch

[g] Abbreviation: Node of uppermost harvestable boll

[h] Abbreviation: Lint

[i] Abbreviation: Population

Table 4.2 Analysis of variance p-values for first bloom height, first bloom nodes, first bloom NAWF[a], final heights, final nodes, first fruiting branch, NACB[b], Nodes of uppermost harvestable boll, gin turnout, and lint yields as affected by plant population (plants ha^{-1}).

Source	Degrees of Freedom	First Bloom HT[c]	First Bloom ND[d]	First Bloom NAWF	Final HT	Final ND	FFB[e]	NACB	NUHB[f]	Turnout	LT[g] Yield
Year	1	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	--	--
Location	1	0.0817	0.0204	0.0124	0.0084	--	0.0046	0.0066	--	--	--
Year x Location	1	0.0006	<0.0001	<0.0001	0.0347	<0.0001	0.0003	--	--	--	--
N rate	4	--	--	--	--	0.0005	--	<0.0001	<0.0001	--	--
Year x N rate	4	--	--	--	--	--	--	--	0.0045	--	--
Location x N rate	4	--	---	--	--	0.023	--	--	--	--	--
Year x Location x N rate	1	--	--	--	--	--	--	--	--	--	<0.0001
Linear Population	1	--	--	--	--	--	--	--	--	--	--
Linear Pop.[h] x Year	2	--	--	--	--	--	--	0.0378	--	--	--

Table 4.2 (Continued)

Linear Pop x location	2	--	--	--	--	--	0.0045	--	--	--	--
Linear Pop x N rate	1	--	--	--	--	--	--	--	--	--	--
Linear Pop x Year x N rate	10	--	--	--	--	--	--	--	--	--	0.0.0100
Linear Pop x Location x N rate	4	--	--	--	--	0.0298	--	--	--	--	--
Linear Pop x Year x Location	1	<0.0001	<0.0001	<0.0001	<0.0001	--	--	--	<0.0001	--	--
Linear Pop x Year x Location x N rate	20	--	--	--	--	--	--	--	--	--	--

[a] Abbreviation: Nodes above white flower
[b] Abbreviation: Nodes above cracked boll
[c] Abbreviation: Height
[d] Abbreviation: Nodes
[e] Abbreviation: First fruiting branch
[f] Abbreviation: Node of uppermost harvestable boll
[g] Abbreviation: Lint
[h] Abbreviation: Population

Table 4.3 Regression coefficients for first bloom height as affected by N rate (kg N ha^{-1}) for trials conducted in Brooksville, Mississippi and Starkville, Mississippi in 2012 and 2013 for each plant population (plants ha^{-1}).

Location	Population	Intercept	Linear	Quadratic
	--plants ha^{-1}--	——Coefficient†——		
Brooksville ‘12	37,050	67.92	0.050‡	-0.0002
Std. Error		1.43	0.021	0.00001
Brooksville ‘12	74,100	67.07	0.050‡	-0.0002
Std. Error		1.43	0.021	0.00001
Brooksville ‘12	111,150	63.83	0.050‡	-0.0002
Std. Error		1.43	0.021	0.00001
Brooksville ‘12	148,200	63.16	0.050‡	-0.0002
Std. Error		1.43	0.021	0.00001
Starkville ‘12	37,050	82.68	-0.050‡	0.00022‡
Std. Error		1.43	0.021	0.00001
Starkville ‘12	74,100	81.43	-0.050‡	0.00022‡
Std. Error		1.43	0.021	0.00001
Starkville ‘12	111,150	83.49	-0.050‡	0.00022‡
Std. Error		1.43	0.021	0.00001
Starkville ‘12	148,200	84.42	-0.050‡	0.00022‡
Std. Error		1.43	0.021	0.00001
Brooksville ‘13	37,050	64.04	0.050‡	-0.00022

Table 4.3 (Continued)

Std. Error		1.43	0.021	0.00001
Brooksville ‘13	74,100	60.88	0.050‡	-0.00022
Std. Error		1.43	0.021	0.00001
Brooksville ‘13	111,150	57.62	0.050‡	-0.00022
Std. Error		1.43	0.021	0.00001
Brooksville ‘13	148,200	58.57	0.050‡	-0.00022
Std. Error		1.43	0.021	0.00001
Starkville ‘13	37,050	64.58	-0.050‡	0.00022‡
Std. Error		1.44	0.021	0.000011
Starkville ‘13	74,100	60.25	-0.050‡	0.00022‡
Std. Error		1.43	0.021	0.000011
Starkville ‘13	111,150	58.68	-0.050‡	0.00022‡
Std. Error		1.43	0.021	0.000011
Starkville ‘13	148,200	56.72	-0.050‡	0.00022‡
Std. Error		1.43	0.021	0.000011

† Where Y=first bloom eights (cm) and X = N rate (kg N ha^{-1})

‡ Coefficient was found significant using Fisher’s protected LSD at ($p \leq 0.05$)

Table 4.4 Regression coefficients for first bloom height as affected by plant population (plants ha $^{-1}$) for trials conducted in Brooksville, Mississippi and Starkville Mississippi in 2012 and 2013.

Location	Intercept	Linear
	Coefficient†	
Brooksville 2012	71.71	-0.00005‡
Starkville 2012	79.23	0.00002
Brooksville 2013	67.03	-0.00005‡
Starville 2013	65.35	-0.00007‡
Standard Error	1.49	0.00001

† Where Y=first bloom heights (cm) and X = plant population (plants ha $^{-1}$)

‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.5 Regression coefficients for first bloom nodes as affect by plant population (plants ha $^{-1}$) for trials conducted in Brooksville, Mississippi and Starkville, Mississippi in 2012 and 2013.

Location	Intercept	Linear
	Coefficient†	
Brooksville 2012	15.14	-0.00001‡
Starkville 2012	15.79	-0.000006‡
Brooksville 2013	15.12	-0.00001‡
Starkville 2013	13.28	-0.00002‡
Standard Error	0.20	0.000002

† Where Y=first bloom nodes and X = plant population (plants ha $^{-1}$)

‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.6 Regression coefficients for nodes above white flower at first bloom as affected by N rate (kg N ha^{-1}) for each plant population (plants ha^{-1}) for 2012 and 2013.

Year	Population	Intercept	Linear
	--plants ha^{-1}--	——Coefficient†——	
2012	37,050	6.44	-0.0005
	74,100	6.26	-0.0005
	111,150	6.01	-0.0005
	148,200	5.93	-0.0005
2013	37,050	7.74	0.0021‡
	74,100	7.09	0.0021‡
	111,150	6.56	0.0021‡
	148,200	6.36	0.0021‡
Standard Error		0.2069	0.0008

† Where Y=nodes above whiteflower and X = N rate (kg N ha^{-1})

‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.7 Regression coefficients for nodes above white flower at first bloom as affected by plant population (plants ha^{-1}) for trials conducted in Brooksville, Mississippi and Starkville, Mississippi in 2012 and 2013.

Location	Intercept	Linear
	——Coefficient†——	
Brooksville 2012	6.75	-0.00001‡
Starkville 2012	6.3917	-0.000002
Brooksville 2013	8.695	-0.00001‡
Starkville 2013	7.8238	-0.00001‡
Standard Error	0.2241	0.0000016

† Where Y=nodes above whiteflower and X = plant population (plants ha^{-1})

‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.8 Regression coefficients for end of season heights as affected by N rate (kg N ha^{-1}) for each location at each year at varying plant populations.

Location	Year	Population	Intercept	Linear
		--Plants ha^{-1}--	——————Coefficient†——————	
Brooksville	2012	37,050	84.53	0.076‡
		74,100	81.42	0.076‡
		111,150	77.73	0.076‡
		148,200	76.54	0.076‡
	Standard Error		1.91	0.012
	2013	37,050	79.62	0.066‡
		74,100	74.65	0.066‡
		111,150	72.32	0.066‡
		148,200	71.80	0.066‡
	Standard Error		1.91	0.012
Starkville	2012	37,050	106.84	0.076
		74,100	104.64	0.076
		111,150	105.01	0.076
		148,200	105.27	0.076
	Standard Error		1.92	0.012
	2013	37,050	82.92	0.079‡
		74,100	78.00	0.079‡

Table 4.8 (Continued)

	111,150	74.63	0.079‡
	148,200	70.38	0.079‡
Standard Error		1.91	0.012

† Where Y=final height (cm) and X = N rate (kg N ha^{-1})
‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.9 Regression coefficients for end of season height as affected by plant population (plants ha^{-1}) for 2012 and 2013 in Brooksville, Mississippi and Starkville, Mississippi.

Location	Intercept	Linear
	Coefficient†	
Brooksville 2012	93.76	-0.00007‡
Starkville 2012	108.07	-0.000008
Brooksville 2013	86.94	-0.00007‡
Starkville 2013	93.79	-0.00011‡
Standard Error	2.94	0.0000029

† Where Y=final height (cm) and X = plant population (plants ha^{-1})
‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.10 Regression coefficients for end of season nodes as affected by N rate (kg N $ha^{-1)}$ for 2012 and 2013 in Brooksville, Mississippi and Starkville, Mississippi.

Location	Intercept	Linear
	——Coefficient†——	
Brooksville 2012	16.71	0.016‡
Starkville 2012	19.56	0.009‡
Brooksville 2013	16.40	0.001‡
Starkville 2013	15.10	0.015‡
Standard Error	0.36	0.003

† Where Y=end of season total nodes (cm) and X = N rate (kg N ha^{-1})

‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.11 Regression coefficients for total nodes at the end of the season as affected by plant population (plants ha^{-1}) for each location and the corresponding N rates.

Location	N Rate	Intercept	Linear
	--kg N ha^{-1}--	——Coefficient†——	
Brooksville	0	17.80	-0.00001‡
	44.8	18.89	-0.00002‡
	89.6	19.40	-0.00002‡
	134.4	18.99	-0.000007‡
	179.2	22.04	-0.00003
Starkville	0	18.62	-0.00002‡
	44.8	19.71	-0.00002‡
	89.6	19.92	-0.00001‡
	134.4	19.71	-0.00001‡
	179.2	19.86	-0.000005
Standard Error		0.73	0.000005

† Where Y=end of season nodes and X = plant population (plants ha^{-1})

‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.12 Regression coefficients for total nodes above cracked boll at the end of the season as affected by N rate (kg N ha^{-1}) for Starkville, Mississippi and Brooksville, Mississippi Locations in 2012 and 2013.

Location	Intercept	Linear
	——Coefficient†——	
Brooksville 2012	3.16	0.018‡
Starkville 2012	4.36	0.011‡
Brooksville 2013	1.66	0.013‡
Starkville 2013	2.26	0.017‡
Standard Error	0.31	0.002

† Where Y= nodes above cracked boll and X = N rate (kg N ha^{-1})

‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.13 Regression coefficients for node of uppermost harvestable boll as affected by N rate for each respectable location, year, and populations.

Location	Year	Population	Intercept	Linear
		--plants ha^{-1}--	———Coefficient†———	
Brooksville	2012	37,050	14.28	0.013‡
		74,100	13.17	0.013‡
		111,150	12.49	0.013‡
		148,200	11.89	0.013‡
	2013	37,050	13.24	0.013‡
		74,100	12.55	0.013‡
		111,150	11.91	0.013‡
		148,200	11.81	0.013‡
Starkville	2012	37,050	15.98	0.013‡
		74,100	15.11	0.013‡
		111,150	15.00	0.013‡
		148,200	14.74	0.013‡
	2013	37,050	12.97	0.013‡
		74,100	11.84	0.013‡
		111,150	11.14	0.013‡
		148,200	10.74	0.013‡
Standard Error			0.33	0.001

† Where Y= node of uppermost harvestable boll and X =N rate (kg N ha^{-1})

‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.14 Regression coefficients for node of uppermost harvestable boll as affected by plant population (plant ha^{-1}) at the respectable nitrogen rates for each year and location.

Location	Year	N rate	Intercept	Linear
		--kg N ha^{-1}--	——Coefficient†——	
Brooksville	2012	0	15.80	-0.00003‡
		45	16.12	-0.00003‡
		90	16.89	-0.00003‡
		134	16.84	-0.00003‡
		179	18.01	-0.00003‡
	2013	0	13.23	-0.00001‡
		45	14.07	-0.00001‡
		90	15.02	-0.00001‡
		134	15.65	-0.00001‡
		179	15.82	-0.00001‡
Starkville	2012	0	15.80	-0.000006
		45	16.12	-0.000006
		90	16.89	-0.000006
		134	16.84	-0.000006
		179	18.01	-0.000006
	2013	0	13.23	-0.00002‡
		45	14.07	-0.00002‡

Table 4.14 (Continued)

	90	15.02	-0.00002‡
	134	15.65	-0.00002‡
	179	15.82	-0.00002‡
Standard Error		0.32	0.000003

† Where Y= node of uppermost harvestable boll and X =plant population (plants ha^{-1})
‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.15 Regression coefficients for gin turnout as affected by N rate (kg N ha^{-1}) and the corresponding intercepts for trials conducted in Brooksville, Mississippi and Starkville, Mississippi in 2012 and 2013.

Location	Intercept	Linear
	Coefficient†	
Brooksville 2012	0.42	-0.00004‡
Standard Error	0.002	0.00002
Starkville 2012	0.41	0.00002
Standard Error	0.002	0.00002
Brooksville 2013	0.42	-0.00003
Standard Error	0.002	0.00002
Starkville 2013	0.45	-0.0001‡
Standard Error	0.002	0.00002

† Where Y= gin turnout and X =N rate (kg N ha^{-1})
‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.16 Regression coefficients for lint yield (kg lint ha^{-1}) as affected by N rate (kg N ha-^{1}) for each respectable year and location.

Year	Location	Intercept	Linear	Quadratic
		Coefficient†		
2012	Brooksville	806.03	4.82	-0.010
	Standard Error	69.09	1.16	0.006
	Starkville	1876.01	3.67	-0.010
	Standard Error	69.08	1.16	0.006
2013	Brooksville	988.40	9.40	-0.028
	Standard Error	69.08	1.16	0.006
	Starkville	1786.82	11.53	-0.028
	Standard Error	69.10	1.16	0.006

† Where Y= Lint Yield (kg ha^{-1}) and X =N rate(kg N ha^{-1})

‡ Coefficient was found significant using Fisher’s protected LSD at ($p \leq 0.05$)

Table 4.17 Regression coefficients for lint yield (kg lint ha^{-1}) as affected by plant population (plants ha^{-1}) for each respectable year and location and N rate (kg N ha^{-1}).

Year	Location	N rate	Intercept	Linear
			Coefficient†	
2012	Brooksville	0	776.58	0.001
		45	935.42	0.000
		90	1111.44	0.000
		134	1334.03	-0.001
		179	1491.93	-0.001
	Starkville	0	1798.64	0.001
		45	1947.54	0.000
		90	2177.52	0.000
		134	2262.38	-0.001
		179	2298.51	-0.001
2013	Brooksville	0	902.02	0.002
		45	1348.94	-0.001
		90	1511.38	0.001
		134	1478.84	0.004‡
		179	1572.61	0.002
	Starkville	0	1635.64	0.002
		45	2329.67	-0.001

Table 4.17 (Continued)

	90	2538.22	0.001
	134	2481.31	0.004‡
	179	2772.50	0.002
Standard Error		112.61	0.002

† Where Y= Lint Yield (kg ha^{-1}) and X =plant population(plants ha^{-1})
‡ Coefficient was found significant using Fisher's protected LSD at ($p \leq 0.05$)

Table 4.18 Fiber Length (cm) and strength (g tex^{-1}) of cotton as affected by N rate (kg N ha^{-1}) for each respectable location and year.

	Brooksville				Starkville			
	2012		2013		2012		2013	
N Rate	Fiber Length	Strength	Fiber Length	Strength	Fiber Length	Strength --(g tex^{-1})--	Fiber Length --(cm)--	Strength --(g tex^{-1})--
--kg N ha^{-1}--	--cm--	--g tex^{-1}--	--cm--	--g tex^{-1}--	--cm--	--g tex^{-1}--	--cm--	--g tex^{-1}--
0	2.76 c	29.58 b	2.74 b	29.84 a	2.84b	30.78 a	2.69 d	28.75 b
45	2.80 bc	30.14 ab	2.78 ab	30.10 a	2.88 ab	30.60 a	2.74 c	29.54 a
90	2.82 b	29.82 b	2.81 a	29.60 a	2.88 a	30.52 a	2.80 b	29.67 a
134	2.83 b	30.13 ab	2.81 a	30.17 a	2.91 a	30.68 a	2.83 ab	29.41 ab
179	2.88 a	30.74 a	2.79 a	29.72 a	2.90 a	30.26 a	2.84 a	29.62 a

Means within a column followed by the same letter are not significantly different at ($P \leq 0.05$)

Table 4.19 Effect of N rate (kg N ha^{-1}) on fiber uniformity of cotton grown across years, locations, and populations.

N rate	Fiber Uniformity
--kg N ha^{-1}--	--(%)--
0	82.9 b
45	83.0 ab
90	83.1 ab
134	83.2 a
179	83.3 a

Means within a column followed by the same letter are not significantly different at ($P \leq 0.05$).

Table 4.20 Effect of Location on micronaire of cotton grown in 2012 and 2013.

Location	2012	2013
Brooksville	4.7 b	5.1b
Starkville	5.1 a	5.2 a

Means within a column followed by the same letter are not significantly different at ($P \leq 0.05$).

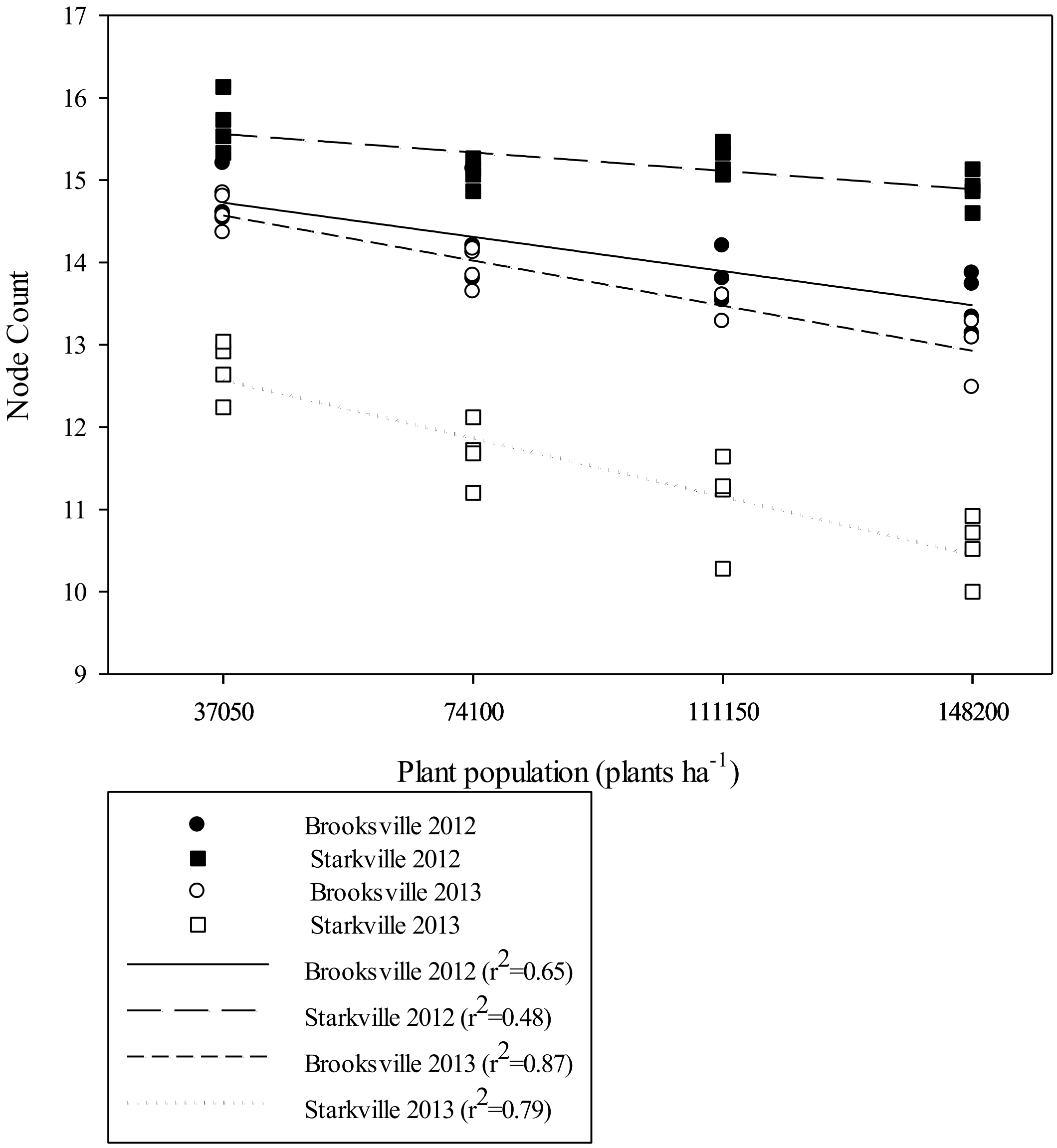

Figure 4.1 Effect of plant population (plant ha^{-1}) on number of nodes located on the mainstem of cotton at first bloom in 2012 and 2013 in Brooksville and Starkville.

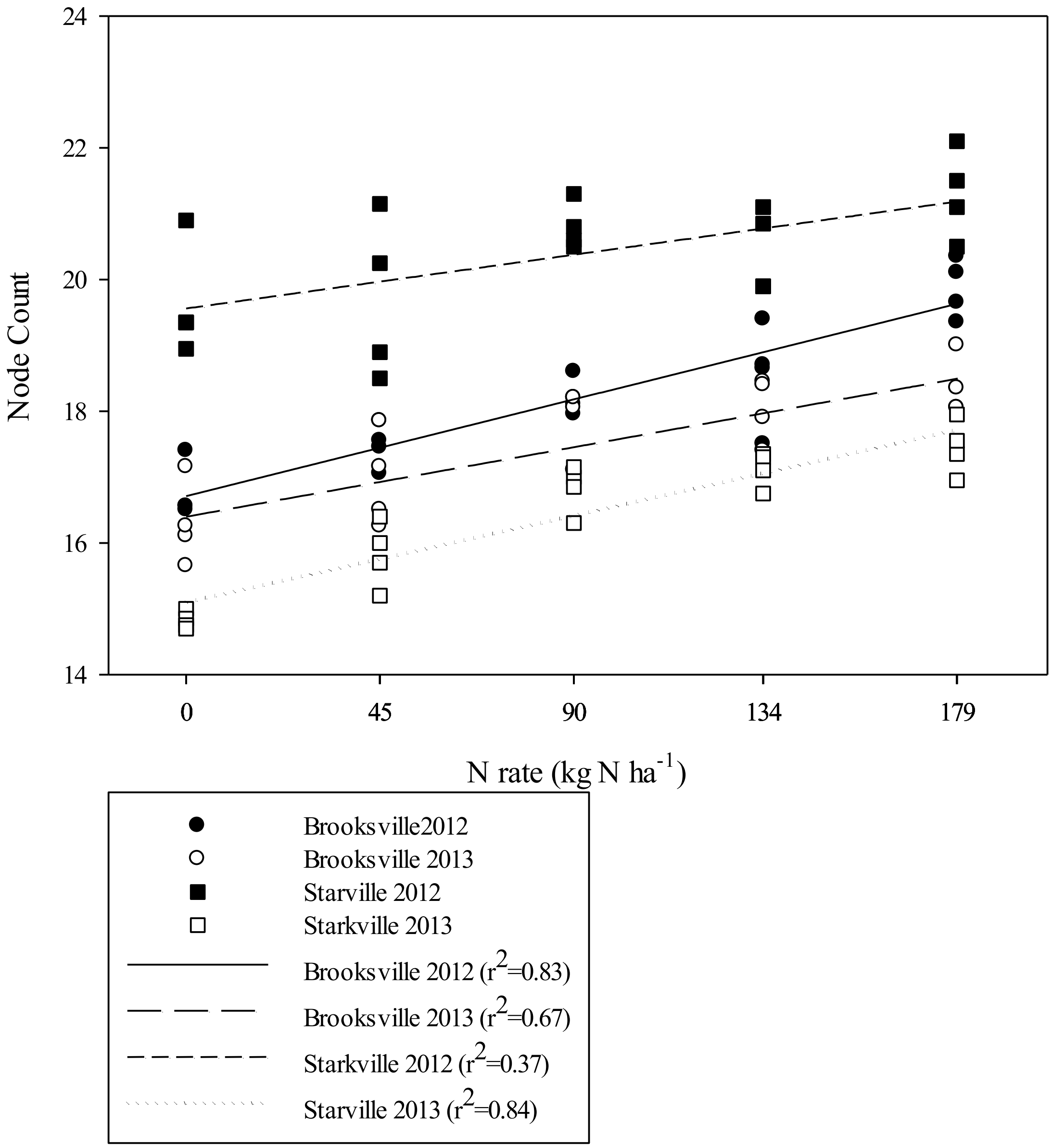

Figure 4.2 Effect of N rate (kg N ha^{-1}) on cotton mainstem nodes at the end of the season in 2012 and 2013 at Brooksville and Starkville.

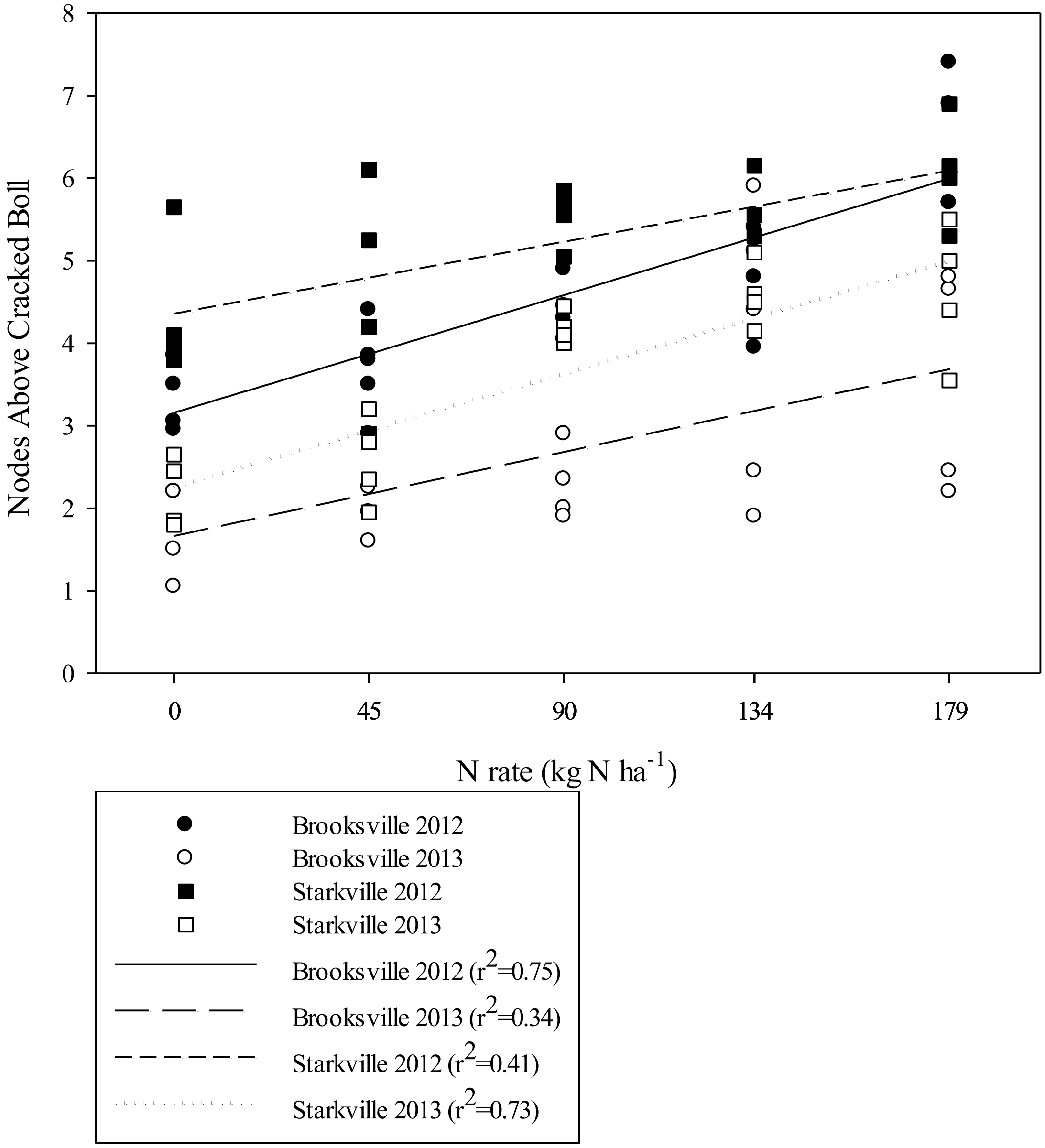

Figure 4.3 Effect of N rate (kg N ha^{-1}) on nodes above cracked boll of cotton grown in 2012 and 2013 at Brooksville and Starkville.

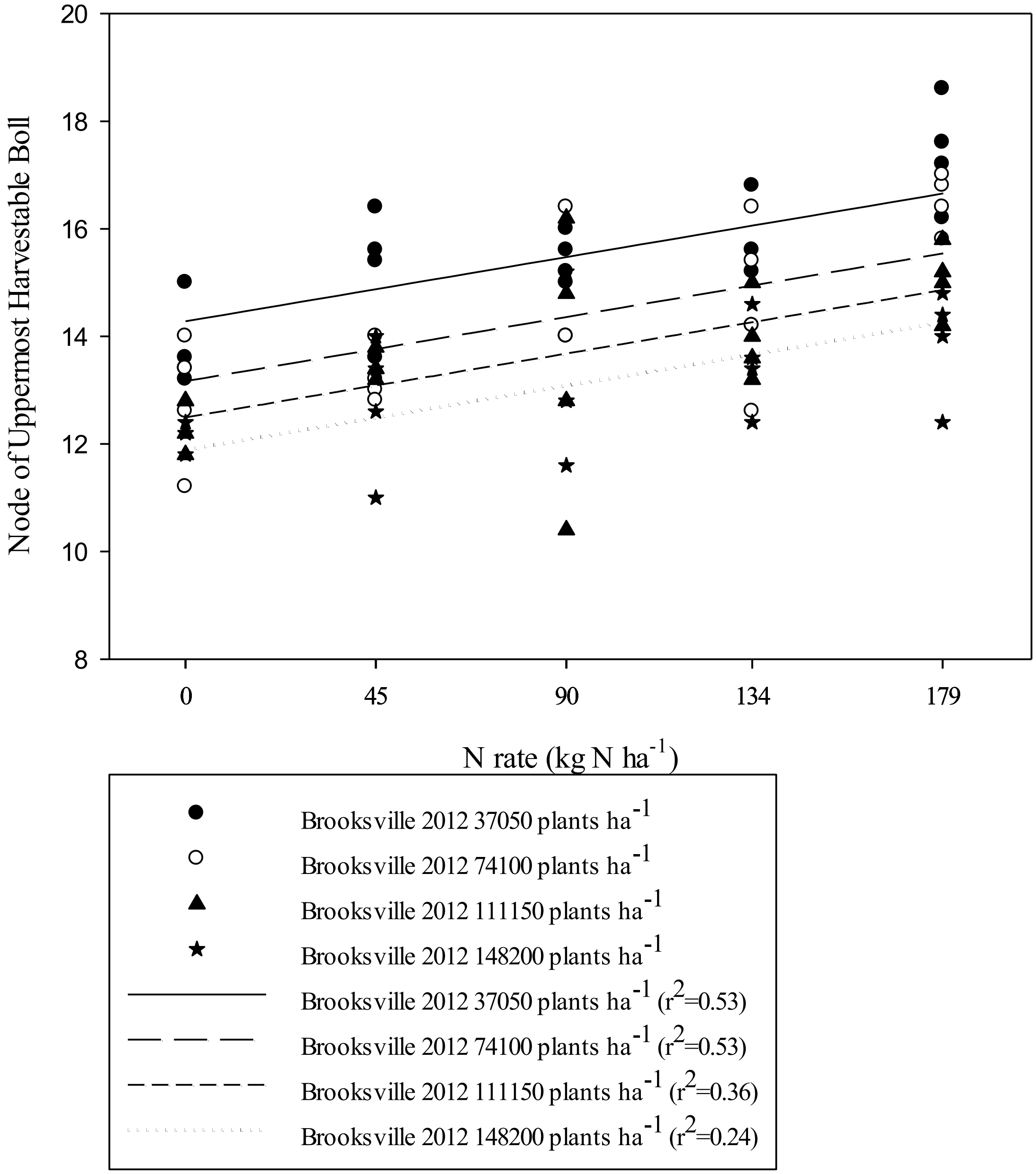

Figure 4.4 Effect of N rate (kg N ha^{-1}) on node of uppermost harvestable boll of cotton at varying plant populations grown in 2012 at Brooksville.

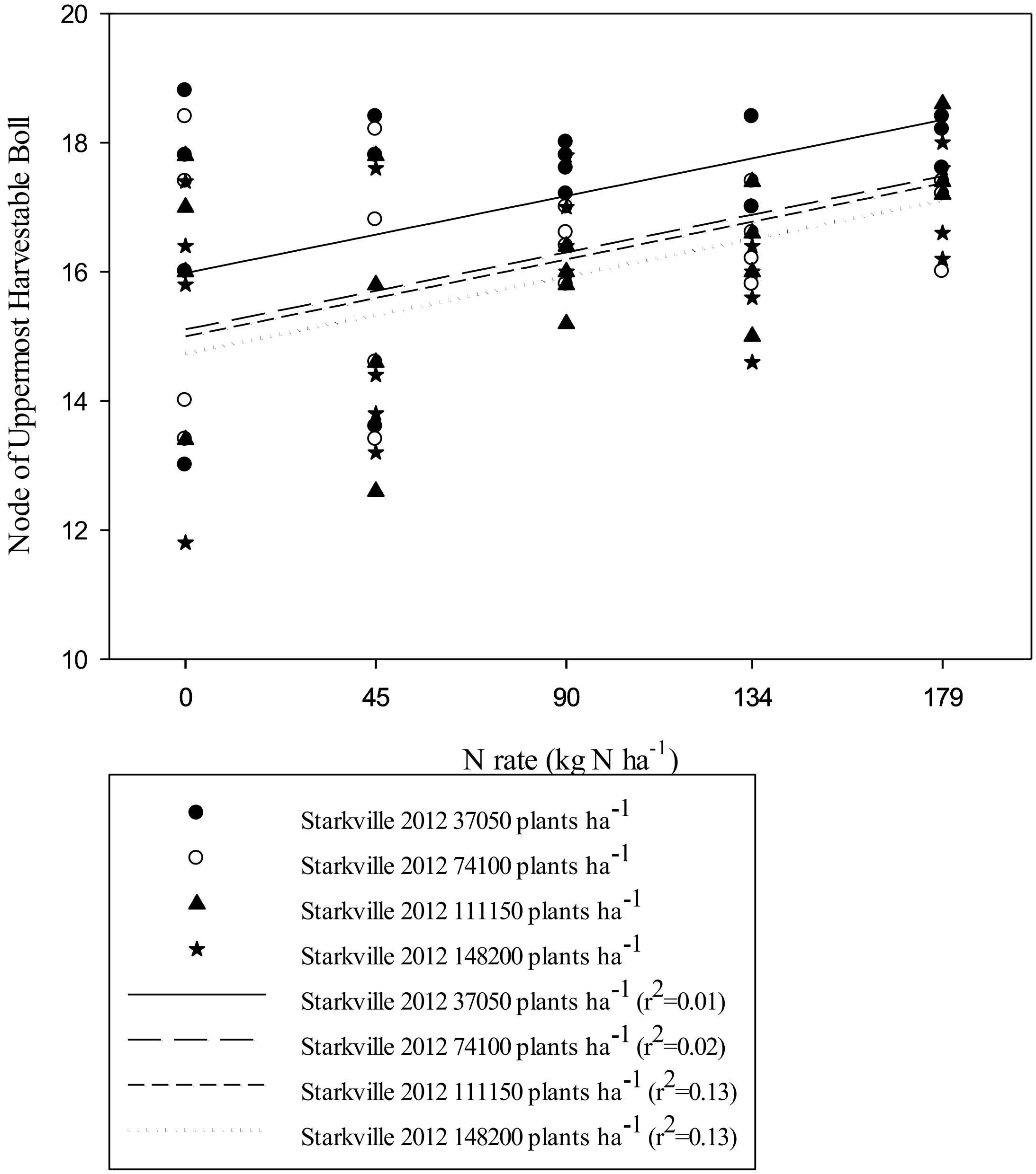

Figure 4.5 Effect of N rate (kg N ha^{-1}) on node of uppermost harvestable boll of cotton at varying plant populations grown in 2012 at Starkville.

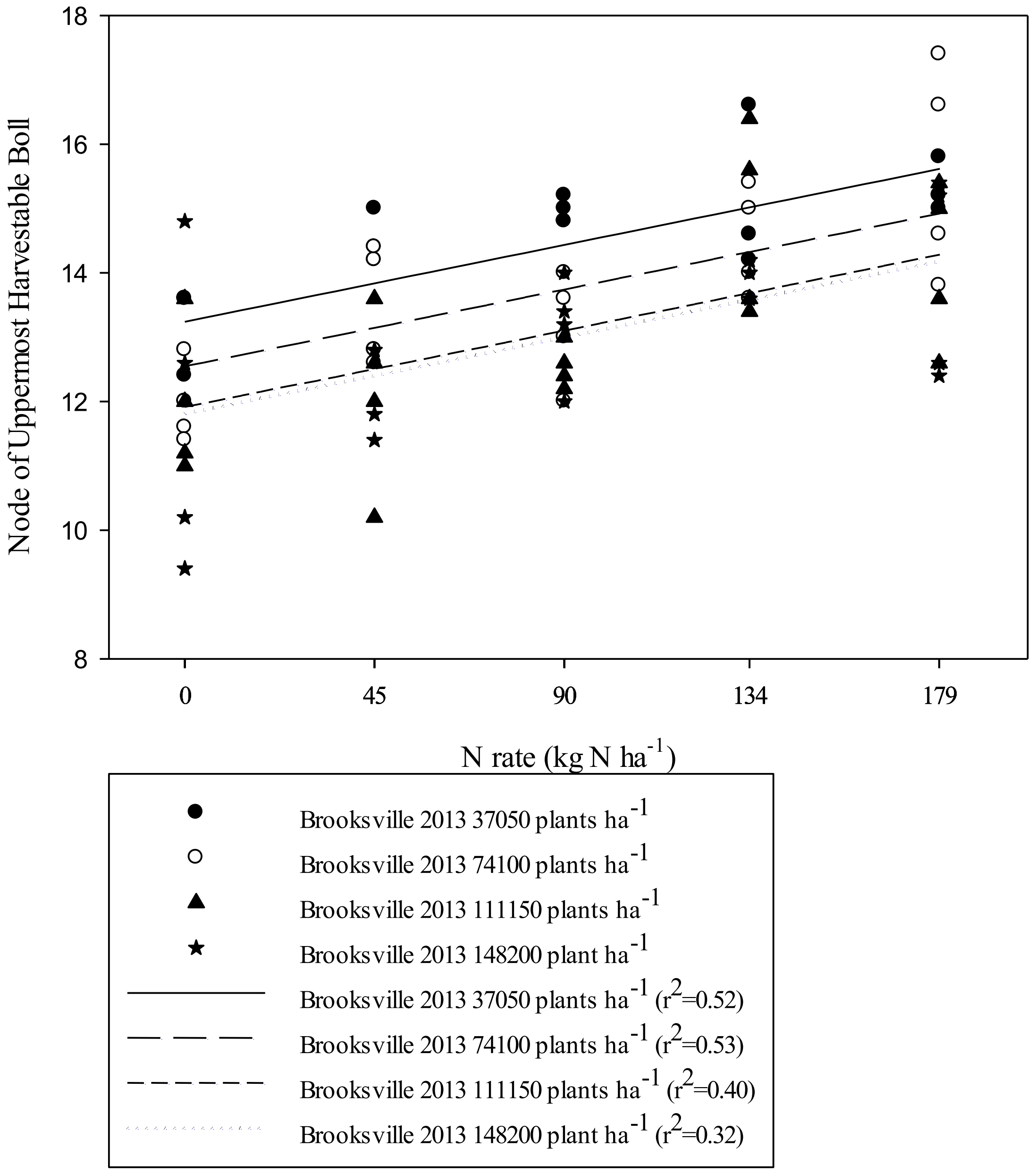

Figure 4.6 Effect of N rate (kg N ha^{-1}) on node of uppermost harvestable boll of cotton at varying plant populations grown in 2013 at Brooksville.

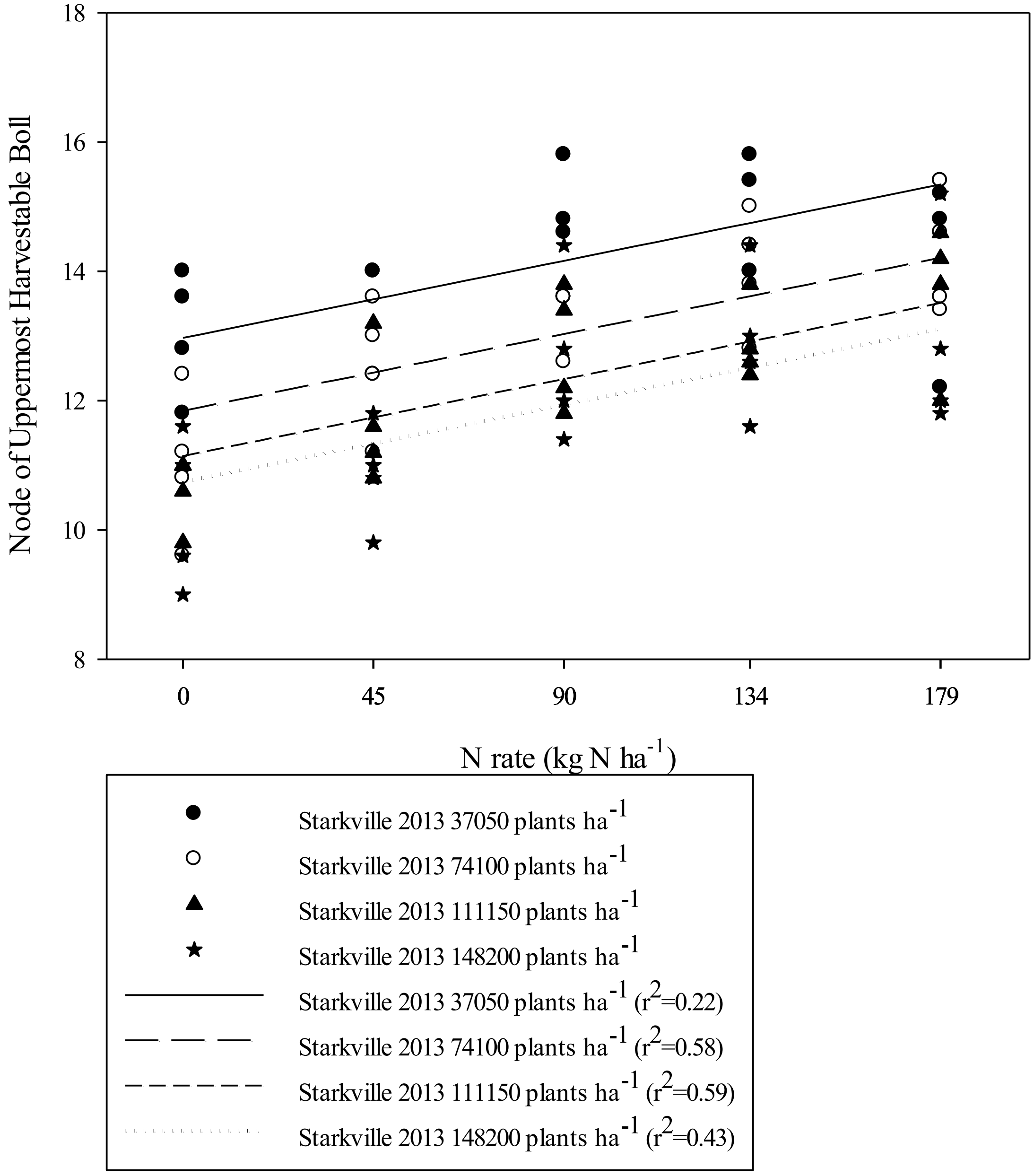

Figure 4.7 Effect of N rate (kg N ha^{-1}) on node of uppermost harvestable boll of cotton at varying plant populations grown in 2013 at Starkville.

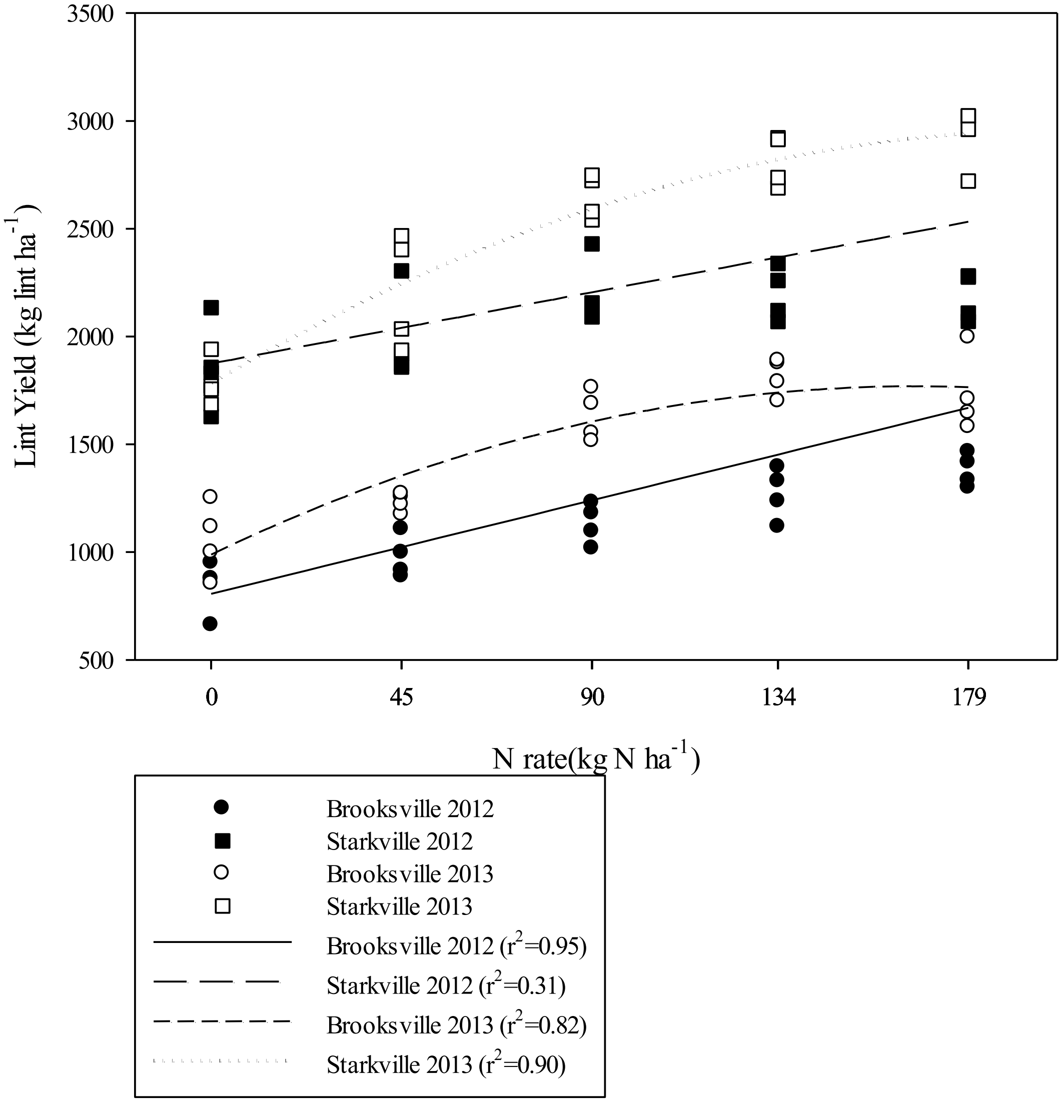

Figure 4.8 Effect of N rate (kg N ha^{-1}) on lint yield (kg lint ha^{-1}) of cotton across populations grown in 2012 and 2013 at Brooksville and Starkville.

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